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MICROPROCESSOR CONTROL OF CHEMICAL APPLICATION TO FORAGES

by

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ABSTRACT

The objective of this study was to design a microprocessor-controlled system for applying a liquid chemical to forage during harvest. A preliminary study was performed to obtain information on the operation and calibration of such a system. A control and a monitor system were designed based on this information.

A sensor to measure the feed rate of forage through a forage harvester, based on the displacement and rotational velocity of the feedroll, was designed and tested. A microcomputer system using a Motorola 6802 microprocessor was designed to control the chemical application, and is feasible. A monitoring system using a ZT-4 driving computer was designed, and is capable of monitoring the system variables.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

Chemical preservatives are applied to forages and hay to inhibit the growth of moulds, decrease losses in nutritional value and dry matter, and decrease the risk of serious heating (Holden & Sneath 1979). The chemical may be applied to the crop at any of many stages of harvest, from prior to cutting until in storage (Benham & Redman 1980). Present chemical application systems do not apply the chemical in proportion to the crop mass; therefore, the required chemical application rate is rarely maintained. Furthermore, the harvest stage at which the chemical is applied and the method of chemical application can greatly influence the chemical losses and chemical distribution through the crop. A chemical application control system which could maintain a constant specified chemical application rate (chemical mass / forage mass) during the harvest could result in chemical and crop savings. The introduction of the chemical to the forage as it is chopped or baled may provide the most effective application control.

To maintain a constant application rate, the control system must have a means of measuring the forage feed rate and controlling the chemical flow rate. Mains (1983) found that the feedroll displacement on a forage harvester is a good indicator of the forage feed rate. Therefore, the feed rate could be obtained by measuring the feedroll displacement. A bank of applicator nozzles on the forage harvester could be switched on and off to simply and

effectively provide the required flow rate of liquid chemical to the forage. A microprocessor is well-suited to control applications such as this, and could be an inexpensive and simple controller.

The objectives of this study were (i) to design and test a forage feed rate sensor based on Mains'(1983) conclusion that the feedroll displacement is a good indicator of the feed rate, and (ii) to design a microprocessor-controlled system to control a liquid chemical application to forage during chopping. The chemical application system should maintain a constant chemical flow rate relative to the forage feed rate. The system should also display, to the operator, the values of forage feed rate, chemical flow rate, application rate, cumulative forage mass, and cumulative chemical.

2. LITERATURE REVIEW

2.1 CHEMICAL TREATMENT OF FORAGES AND HAY

In northern climates, nearly half of the annual forage crop must be preserved as hay or silage. Climatic conditions during harvest often result in hay losses (Harrison 1983). Hay which is baled at moisture contents above 20% may undergo heating, moulding, and deterioration, and is possibly responsible for some health problems in cattle and farmers (Charlick et al. 1980, Benham & Redman 1980). There can also be substantial losses in silage due to moulds. A 15 to 90 cm (6 to 36 in) layer of spoiled silage is common on the top of poorly sealed horizontal silos (Anon. 1979). Losses in tower silos are not as significant because of the reduced area of exposed silage; however, the capital cost of tower silos is considerable. The less costly horizontal silos are more common in western Canada.

Chemical preservatives can inhibit the growth of moulds, decrease losses in feeding value and dry matter, and decrease the risk of serious heating in damp hay and forages (Holden & Sneath 1979). This can be accomplished by the reduction of available water, reduction of oxygen concentration, alteration of pH, or destruction or inhibition of fungi, moulds, and bacteria (Benham & Redman 1980). Several chemicals are being used or investigated as preservatives for forages or hay. These include anhydrous ammonia (Kuntzel et al. 1979), proprionic acid (Nehrir et

al. 1978, Knapp et al. 1976), ammonium bis-propoanate (Holden & Sneath 1979), and sulphur dioxide (Mathison et al. 1979, 1981). Several chemicals are effective as preservatives, and the use of hay preservatives can be cost effective (Klinner & Holden 1978).

2.2 CHEMICAL APPLICATION SYSTEM

Chemical preservatives may be applied to the standing crop, during mowing, raking, baling or chopping, or in storage (Benham & Redman 1980). Application of the chemical to the forage as it passes through the harvester or hay baler may permit the most effective application control (Klinner & Holden 1978). The limit on the power available to the harvester (and to a lesser extent, the baler) ensures a relatively even forage feed rate past the applicator. Furthermore, the physical sensing of some component of the harvester or baler which changes with the feed rate could provide for the measurement of the forage and subsequent adjustment to the chemical flow rate. Applying the chemical at the forage harvester also permits better mixing of the chemical into the forage than if the chemical were applied in storage. In addition, it minimizes any chemical losses due to exposure which would occur if the chemical were applied prior to pickup. In-field chemical application has a disadvantage over in-store application in that it requires that the chemical be transported in the field. Alternatively, chemical application done in-store is

difficult, time consuming, and in general, impractical. The application of preservatives during baling or chopping involves the least change to the harvesting system (Benham & Redman 1980), and for this and other reasons already noted, the study shall focus on the application of a chemical to forage as it is chopped.

Present chemical (preservative, fertilizer, herbicide) application systems depend upon the operator to make any adjustments in the chemical flow rate with respect to the feed rate (eg. anhydrous ammonia application to corn silage), or maintain a constant chemical flow rate with respect to time or vehicle ground speed (eg. herbicide, fertilizer application) (Bournas 1969, PAMI 1980, 1982). Any of these systems, if used for applying a chemical to forage during chopping, could result in an uneven and inefficient chemical distribution throughout the forage.

The requirements of an idealized chemical application system for a forage harvester are that :

1. the chemical be applied evenly throughout the mass,
2. the chemical loss be minimized,
3. large variations in feed rate be recognized and the chemical flow rate adjusted accordingly,
4. the system be simple, economical, and easily installed on the harvester,
5. and finally, the safety of the operator not be compromised, an important consideration if the chemical is toxic (Benham & Redman 1980).

With information provided by a feed rate sensor on a harvester, a microprocessor could determine the optimal chemical flow rate at any time and activate the solenoids for the corresponding applicator nozzles. With such a system the chemical would be distributed through the forage based upon the input from the feed rate sensor. The accuracy of the system would be limited only by the accuracy of the sensor, and by the available applicator nozzles.

A microprocessor-controlled system with a range of applicator nozzle sizes and an adequate feed rate sensor should be capable of handling large feed rate fluctuations, and adjusting the chemical flow rate to maintain a constant application rate. Microprocessors have been used in numerous control applications similar to this one (Kruse et al. 1983, McLendon et al. 1983), and are practical and relatively inexpensive. A microprocessor-controlled system has a much faster response time than any manual system. In addition, the microprocessor, with a simple and relatively standard support system, can accurately and rapidly make decisions based upon numerous variables (Page et al. 1977). The designed microprocessor control system might also be adapted to control the application of chemicals to hay as it is baled, or possibly to grain as it is combined or elevated for storage.

2.3 FORAGE FEED RATE MEASUREMENT

A chemical application control system requires a sensor which is capable of rapidly and accurately measuring the forage feed rate through a forage harvester. There are three methods of measuring forage feed rate when picking up a windrow (Mains 1983). The first is to continually weigh the forage wagon into which the forage is being collected. The second method is to measure some component of the forage harvester which varies with the forage feed rate. The third possible alternative is to measure the swath height, which according to Mains (1983), has been found to be related to the throughput of hay in a baler.

Research has been done on the second method by measuring the displacement of the rear upper feedroll of a forage harvester as the feed rate varies (Mains 1983). The feedroll displacement was found to be a good indicator of the mass flow rate of crops through a forage harvester. High coefficients of determination were found for the regression equations predicting feedroll displacement as a function of feed rate and dry matter content. The form of these equations is:

$$f = a + b \cdot y + c \cdot m \text{ (corn)} \quad \text{2.1}$$

$$f = a + b \cdot y + c \cdot m + d \cdot y \cdot m \text{ (alfalfa)} \quad \text{2.2}$$

where f = forage feed rate (kg/min)

y = feedroll displacement (mm)

m = percentage of crop dry matter

a,b,c,d = constants for each particular crop.

Mains (1983) found a poor correlation between the summation of the feedroll displacement and the cumulative amount of crop harvested over a short time interval (one second). He noted that the poor correlation was probably caused by short-term variation of the feedroll displacement, and suggested that a better correlation could probably be obtained if the time period were longer (ten seconds). However, a ten second interval represented up to 23 m (77 ft) of windrow in Mains' (1983) research. Any feed rate variation within this length of windrow would not be detected if the measurements were integrated over ten seconds. Mains (1983) correlated the average feedroll displacement during a given time interval to the forage throughput during the same time interval. However, there is a time lag between the forage displacing the feedroll and exiting the harvester to be weighed. This time lag will comprise a larger proportion of a one second measuring interval than a ten second interval; hence, the error will be less, and the correlation will be greater during the longer time interval. In addition, Mains calculated the data for the ten second intervals by averaging the data from ten consecutive one second intervals. Therefore, the ten second intervals would result in fewer data points with less variation, and hence, a better correlation.

The constants for these equations vary with each crop. In addition, each particular forage harvester, and the feedroll spring tension on the harvester, would necessitate

a unique set of constants. To use these equations, it would probably be necessary to calibrate each harvester being used with each crop being harvested.

A microprocessor-controlled chemical application system, which is based on Mains' (1983) conclusion that the feedroll displacement is a good indicator of the forage feed rate, would require a device capable of measuring the feedroll displacement and communicating this value to a microprocessor. Transducers or sensors change physical quantities such as motion into electrical signals which can be transmitted to a computer or a recording system. Common transducers measure displacement, force, pressure, temperature, light, and magnetic fields (Henry 1975, Barden 1982, Spitzer 1972, Malmstadt 1981).

Many transducers are available for measuring displacement. The LVDT (linear variable displacement transformer) is an analog device for sensing displacement, and is commonly used in experimental and developmental work (Henry 1975). The versatility of the LVDT makes it well-suited to research; however, it is relatively expensive and requires analog to digital signal modifications if it is to be connected to a microprocessor (Henry 1975). Optical and magnetic sensors have a digital output, and are more popular in monitoring and control applications (Morris 1980, Anon. 1980). They can be relatively inexpensive, and their digital output signal is more readily compatible with a microprocessor system than the analog output from some of

the other types of transducer. In addition, the absence of moving parts in these sensors allows them a long life, not limited by wear or fatigue.

Optoelectronic light sources (usually light emitting diodes) and detectors (usually photo-transistors) are widely used as displacement or velocity sensors. Honeywell (1976) and Anon. (1980) discuss the two types of optoelectronic sensor. In the first type, reflective object sensors, the light emitter and detector are located side by side. When a reflective surface is placed in front of them, the light beam from the emitter reflects onto the detector, inducing an output voltage from the detector. When the reflective surface is moved or blocked, the voltage drops. The second type of optoelectronic sensor is more common than the reflective object sensors. With this sensor, the emitter and detector are located opposite one another with colinear axes, so that an output voltage is induced from the detector when a transparent medium is between them. When an opaque object blocks the path between the emitter and detector, the detector's output voltage drops.

Malmstadt et al. (1973) and Morris (1980) describe several applications, including displacement measurements, in which an encoded disk or plate containing opaque and transparent sections rotates between an emitter and detector. These encoding devices can make either "absolute" or "incremental" measurements. Absolute encoders use disks with opaque/transparent patterns which can simultaneously

actuate several detectors; together, these detectors output a digital word representing the absolute position of the encoding device. Each transparent section on the disk allows passage of a light beam from an emitter to the corresponding detector, which then outputs a "high" voltage. An opaque section blocks the light beam, and the detector output is "low". Several coding techniques are used, including a "straight binary code", "Gray code", and "sine-cosine code" (Malmstadt 1973). Incremental encoders contain a uniform pattern of equally spaced radial lines (opaque lines on a transparent surface, or vice versa), which results in detector output voltage pulses as the disk rotates.

Optoelectronic devices can be impractical in dirty and dusty environments. In these situations, a magnetic (variable reluctance) pickup sensor (Anon. 1980, Honeywell 1976) is often used for measuring motion. The simplest magnetic pickup consists of a wire coil around a permanent magnet. A ferrous metal object (a magnet is often used) approaching or moving away from the sensor changes the permeance of the magnetic field. Since the sensor output voltage is proportional to the rate-of-change flux through the coil, magnetic pickups detect moving targets only. As the object's velocity approaches zero, the voltage change for the output pulse becomes too small to be measured. Magnetic sensors require no external power source, and have successfully measured speeds up to 600,000 rpm. They have the advantages over other sensors of being capable of

operation in temperature ranges beyond those allowed by solid state devices, due to the absense of electronic elements, and being impervious to shock.

Magnetic sensors are commonly used as displacement and velocity sensors in agricultural machinery. A magnet is mounted on the driveshaft or a wheel, and is detected on every rotation by a nearby detector which outputs voltage pulses with a frequency proportional to the vehicle velocity, or a count proportional to the distance travelled. These sensors are used in sprayer control systems (J&H 1982) and many other machinery monitor and control applications where information on the vehicle speed or area covered (as calculated from the displacement and a specified width of the machine) is required. In addition, they are used for monitoring rotating grain or fertilizer shafts during seeding (Senstex 1983).

A second type of magnetic sensor, the Hall-effect sensor, is described by Honeywell (1976). In a Hall-effect sensor, a constant control current is passed through a thin strip of semiconductor material (Hall generator). The contacts are placed across the narrow dimension of the strip, and a small voltage appears across them as a magnet's field is directed at right angles to the face of the semiconductor. The Hall voltage reduces to zero again as the magnet is removed. If the current flow through the element is held constant, the Hall voltage is proportional to the magnetic field. Since the Hall effect senses a magnetic

field, the magnet doesn't have to be moving in order for the device to operate. Hall-effect proximity sensors are used as position indicators and limit switches for the stacking tables on Sperry New Holland's microprocessor-controlled hay bale stacker (Honeywell 1979).

2.4 MICROPROCESSORS - MONITORS AND CONTROLLERS

A computer consists of an arithmetic logic unit (ALU) which performs arithmetic and logic operations, input/output circuits, gates and registers to control and coordinate the operations of these circuits, and memory for storage of programs and values (Greenfield & Wray 1981, Hinkle 1982). A minicomputer is of a smaller size and has more limited capabilities than a full-size computer; however, it performs the same functions. Smaller than a minicomputer, the microcomputer can also provide all of the functions of a larger computer, but it is usually dedicated to one use or control function. The microprocessor is one component of a microcomputer, and was produced when the above-mentioned integrated circuits (ie. gates, registers, and ALUs) were combined into a single component or chip. This chip includes most of the functions of a computer; however, it cannot function by itself (Greenfield & Wray 1981).

Microcomputers can be used as monitors (indicators) or as controllers (Hinkle 1982). In either case, the microprocessor reads the input and calculates an output based on these inputs. In a monitoring situation, the

microprocessor would read the signal from a transducer, convert the value into a more useful number, and display this number. In a controlling capacity, the microprocessor would read the input signal(s), make a decision regarding the output (ie. switch "on" or "off") based on calculations or logic, and send a control word capable of implementing this decision to the proper output device. It could also display an appropriate value.

Microcomputers are useful in applications which require rapid and precise control or data acquisition (Walker 1981). A microcomputer has numerous advantages over a mechanical or manual data collection or control system. These advantages include fast data collection during complex tests or experiments, exact timing and triggering of simultaneous or sequential events, automatic control of numerous devices or operations, versatility of operation through program control, and ease of interfacing to printers and recording systems (Walker 1981). In control applications, a microcomputer system is superior to mechanical or hard-wired logic systems because of its versatility and adaptability. A microcomputer system can be simply and quickly modified, by reprogramming, to function in a new or different situation. A mechanical or hard-wired logic system could also be adapted; however, it would be more time-consuming and costly to rebuild or structurally modify the system.

Microprocessors are becoming more and more common in everyday applications, and are improving the efficiency and

economic operation of many systems. They are being used in many monitoring and control systems in agriculture (Isaacs 1982). Sprayer Control System (Raven Industries 1983) uses a microprocessor to monitor the vehicle speed of an agricultural sprayer, and control the flow rate of a chemical with a regulating valve to maintain a specified application rate per unit area. A microprocessor is also available for installation on combines to monitor grain loss and ground speed (J&H 1982), and a microprocessor is being used to control a hay bale stacker (Honeywell 1979).

Microcomputers are becoming increasingly popular as monitors in automobiles also. A driving computer with a clock, magnetic detector and magnets on the driveshaft, and a flowmeter in the fuel line can measure the time and distance driven and the fuel used on a trip. It can calculate the fuel remaining in the tank, the current or average fuel consumption rate, the fuel needed on a trip, and the distance which can be travelled on the remaining fuel (Zemco 1983).

Agricultural machinery research has included the investigation of such diverse microprocessor control applications as the use of a groundspeed controller for a combine (Kruse et al. 1983), an apple-harvester microprocessor-based steering control system (McMahon et al. 1982), and the microprocessor control of alcohol fuel fumigation (Walker 1981).

3. PRELIMINARY STUDY

3.1 PROCEDURE

3.1.1 OBJECTIVE

Prior to the design of a chemical application system controlled by a microprocessor, information and data on the variables influencing such a system are necessary. The preliminary study consisted of "system trials" and "calibration trials". The system trials were done on private farms, and examined the operation of a controlled chemical application system. The calibration trials, done at the University of Alberta's Ellerslie Research Station, calibrated the feedroll displacement to the forage feed rate. The calibration trials were done with barley and alfalfa at a range of moisture contents and theoretical lengths of cut (Kepner et al. 1972).

For this preliminary study, a chemical application system ("direct system") for sulphur dioxide (Harrison 1983) was modified for control by a minicomputer. Mains (1983) had found that the feedroll displacement on a forage harvester was a good indicator of forage feed rate. Therefore, the modified application system was designed to maintain a constant chemical application rate with respect to the forage feed rate as measured by the feedroll displacement. The pressure in the modified system was monitored, and the cumulative amount of chemical applied was calculated.

3.1.2 EQUIPMENT AND INSTRUMENTATION

The "direct system" developed by Harrison (1983) for applying sulphur dioxide is readily adaptable to allow control of the flow rate. The direct system was modified for use in this preliminary study by replacing the single solenoid valve and nozzle by a bank of solenoid valves and corresponding nozzles. The solenoid valves, and consequently, the chemical flowrate from the nozzles, were controlled by a minicomputer. The number of nozzles used, and their capacities, were chosen to allow a flexible and wide range of chemical flowrates. This flow range would accomodate a reasonable spread of forage feed rates at a chemical application rate of 0.35% (wet weight basis) (Mathison et al. 1979). An application rate of less than 0.35% would not adequately protect the forage, and an overapplication of chemical would have no benefit and would be wasteful. This modified system was installed on a forage harvester (Hesston 7150) and used to control the application of sulphur dioxide to forage during chopping.

During both the system trials and the calibration trials, the minicomputer and a paper tape punch collected data on the feedroll displacement, cumulative mass of forage harvested, chemical line pressure, and chemical applicator nozzles in use. The minicomputer controlled the applicator nozzles, and therefore, the chemical application rate, based upon the forage feed rate as indicated by the feedroll displacement. The minicomputer used was a MINC PDP-11/23

with full analog and digital interfacing capabilities. This general purpose minicomputer was used for these preliminary study trials since a minicomputer is more versatile, and easier to reprogram, than a dedicated microprocessor.

The control system used in this preliminary study, and subsequently used in the designed application system, was a single-variable feed-forward open-loop control arrangement (Appendix I).

A tractor (Massey Ferguson 2805) towed the forage harvester, the nurse wagon with the chemical tanks, and an instrumentation van. The forage wagon collecting the harvested forage was towed alongside the harvester by a second tractor (Figure 3.1). This forage wagon was supported by four load cells to allow continuous monitoring of the mass of forage in the wagon (Harrison 1983).

The displacement of the upper front feedroll on the forage harvester was measured with an LVDT. An LVDT was used for this measurement since it was readily available and could be simply and quickly installed in the system. Since the maximum displacement of the feedroll (17 to 18 cm) exceeded the maximum possible displacement of the LVDT (6.4 cm), a cantilever beam arrangement was used to get a LVDT displacement smaller than, but proportional to, the feedroll displacement. One end of a 38.1 cm (15 in) cantilever rested on, and displaced with, the upper front feedroll. The other end was hinged to a stationary lid on the forage harvester (Figure 3.2). The LVDT measured the

Figure 3.1 Forage harvesting for data collection and and chemical application control during the preliminary study.

Figure 3.2 LVDT (feedroll displacement measurement) and chemical applicator nozzles during the preliminary study.

displacement of the cantilever at one third of the cantilever length from the hinged end.

Four spray nozzles for applying the chemical were located between the table auger and the front feedrolls of the forage harvester (Figures 3.2, 3.3). The feed rate sensor (LVDT) was located on the front upper feedroll, thus the chemical applicator nozzles were as close as possible to the sensor influencing their operation. The nozzles were rated at 0.38, 0.57, 0.76, and 1.14 L/min (0.10, 0.15, 0.20, and 0.30 USGPM) at a pressure of 415 kPa (60 psi). At these ratings, the four nozzles would provide the proper chemical flowrate for feed rates from 9 to 27 t/h when used individually, and for feed rates up to 68 t/h when all the nozzles were simultaneously active. In addition, the gradation of nozzle capacities allows a maximum possible deviation of 25% from the required flowrate at any instant (assuming that the feed rate is not less than 7 t/h), and the average deviation over a length of time should be less than this. The calibrated capacities (Appendix A) differed slightly from the rated capacity values, and the maximum possible deviation is lower with the calibrated values. As in the direct system (Figure 3.4), the solenoid valves were located immediately behind the nozzles, since the sulphur dioxide freezes the line between the nozzle and the solenoid valve upon shut-off. A pump was located between the chemical tank and the solenoid valves, and a back pressure regulating valve maintained the pressure at approximately 550 kPa (80

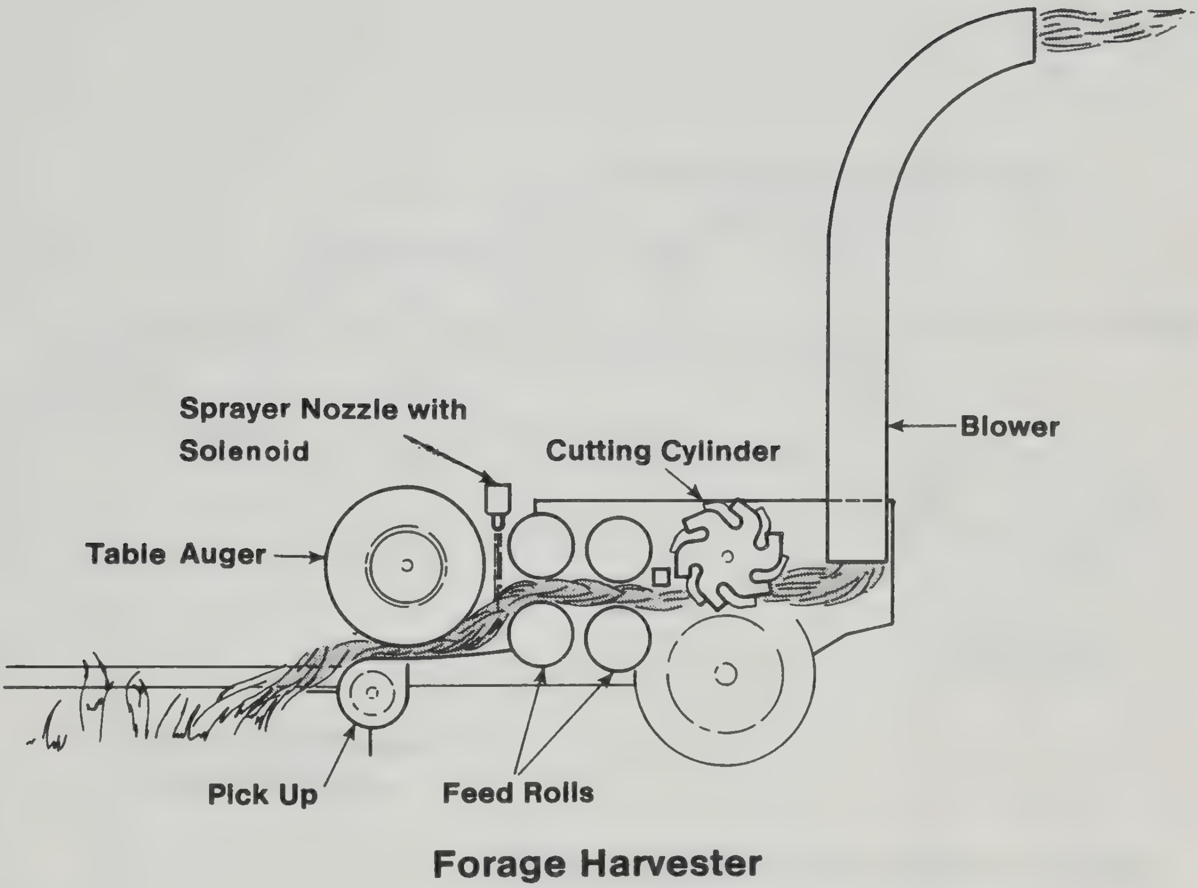

Figure 3.3 Diagram of the forage harvester.

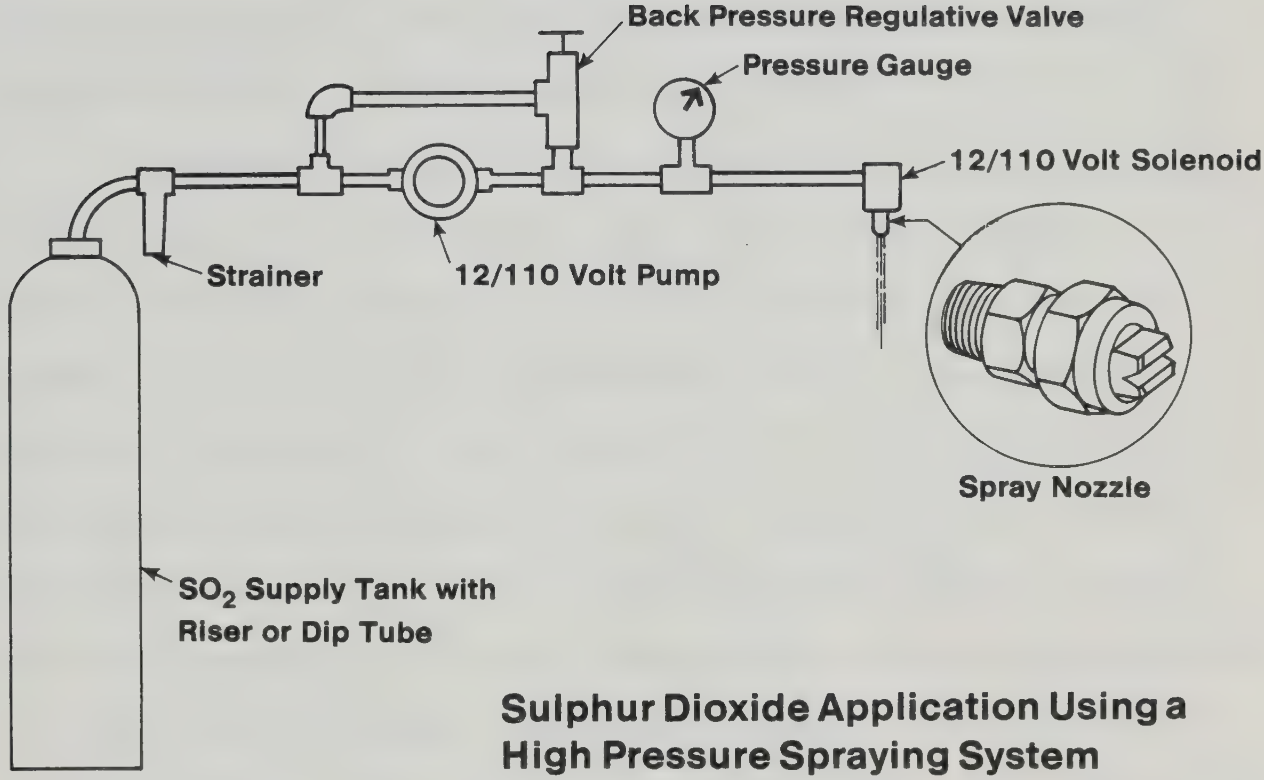

Figure 3.4 Diagram of the chemical flow system.

psi) (Harrison 1983). A pressure transducer was located between the pump and the solenoids to monitor the line pressure for fluctuations which could affect the chemical flowrate. The calibrations for the LVDT, forage wagon load cells, applicator nozzles, and pressure transducer are recorded in Appendix A. The nozzle calibrations were done with water, and consequently, provided approximate or preliminary flow values. Since the sulphur dioxide "flashes" (partially goes from a liquid to a gas state) as it passes through the nozzle, the calibrations should be done with sulphur dioxide to obtain accurate values.

A schematic of the wiring can be seen in Figure 3.5. The minicomputer, the paper tape punch, and a signal conditioner were located in the instrumentation van. The signals from all of the transducers (LVDT, load cells, pressure transducer) were wired into the signal conditioner. The signal conditioner provided the excitation voltages for the transducers, as well as amplifying the output signals. The solenoid-control output lines from the minicomputer were connected to the signal conditioner, as well as to the solenoid valves. From the signal conditioner, the LVDT, load cells, and pressure transducer signals were sent to the MINC minicomputer. The paper tape punch also recorded these transducer signals, and the solenoid-control line voltages, which indicated the active nozzle(s). The signals going to the paper tape punch were directed from the signal conditioner into an integrator to average the signals over

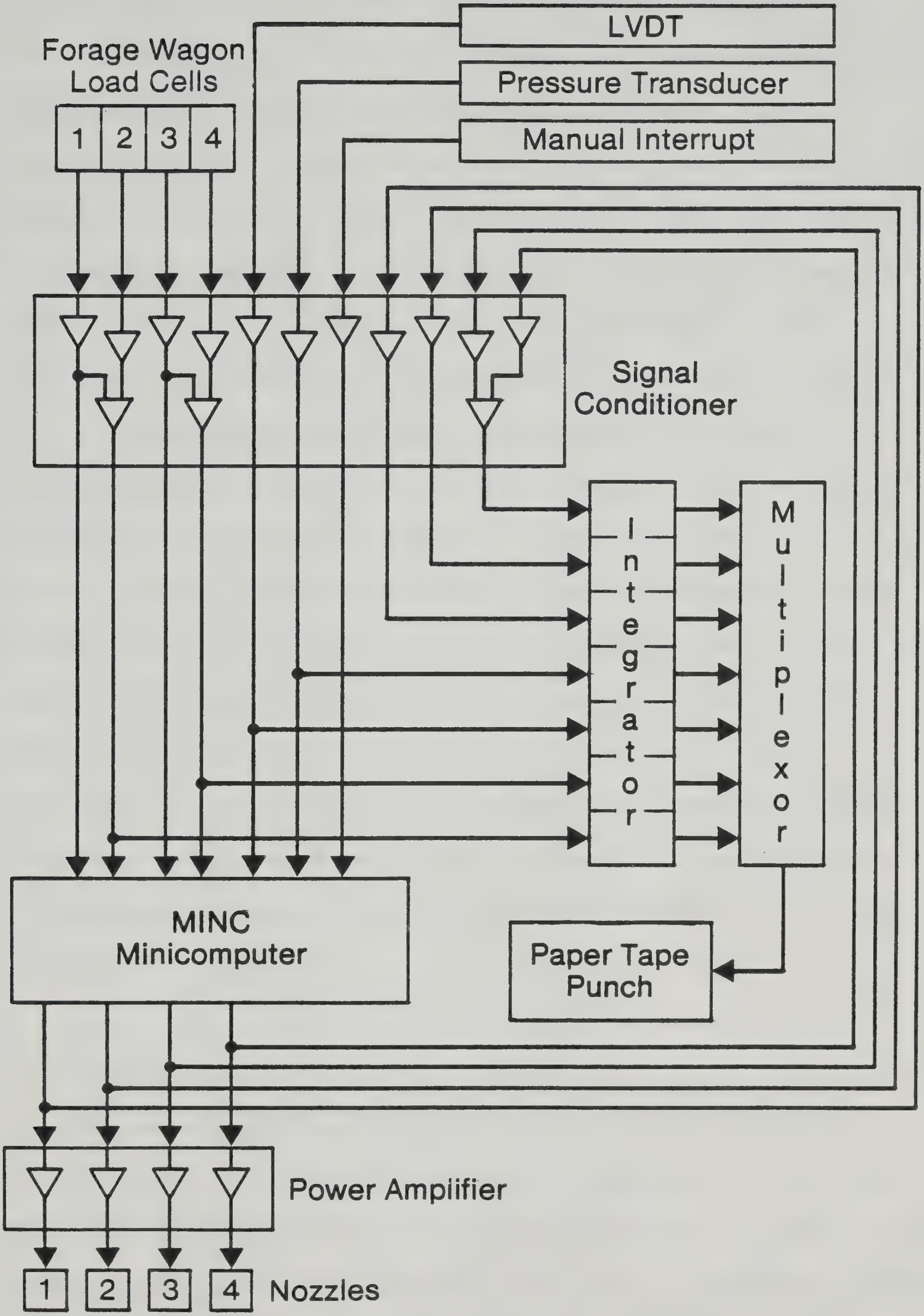

Figure 3.5 Schematic of the wiring in the preliminary study.

each sampling period, then into a multiplexer which coordinated their transfer to the paper tape punch.

All signals to the minicomputer and paper tape punch were analog or were treated as analog signals. The solenoid-control outputs from the minicomputer were digital signals. Since the voltage and current output from the MINC minicomputer was not large enough to activate a solenoid valve, the output signals were routed through a power amplifier (Appendix B), and then to the solenoid valves.

A grounding problem was encountered with the instrumentation such that the minicomputer and the signal conditioner were at different grounds. This resulted in all of the signals which were sent to the minicomputer being offset from the output signal of the signal conditioner by a constant voltage. Since it was not possible to obtain a common ground for the signal conditioner and the minicomputer, an additional wire was run from the signal conditioner to the minicomputer, allowing the minicomputer to read the voltage difference between grounds, and correct for it.

3.1.3 MINICOMPUTER PROGRAM

A listing of the FORTRAN program used by the MINC minicomputer for this research is in Appendix C. Both the FORTRAN and BASIC languages are available on the MINC. The FORTRAN language was chosen for use since a FORTRAN program operates faster than a BASIC program, and can operate

without accessing the disk drives on this system. The disk drives were used only to initially load the program, since the disks or disk heads can be damaged if the unit is operated while in motion.

The minicomputer program read all of the input lines and set the output lines once every 13 to 14 seconds. The readings of the LVDT and forage wagon load cell signals were used to determine which nozzles were to be turned on. The pressure transducer readings were used in to monitor the system performance.

After initialization of the variables, the program entered a continuous loop which was only halted by an interrupt, manually set at the signal conditioner. The program loop began by sampling the signal from the LVDT one hundred times, and averaging the readings. These one hundred readings were spaced over a 5 second interval. The LVDT sampling interval had to be long enough to be representative of the entire time period of the program loop and to yield a good correlation between the feedroll displacement and the forage feed rate. The interval had also to be short enough that an excessive amount of forage had not been harvested before the sampling was completed. The program loop required approximately 9 seconds to execute the other functions, and 5 seconds of sampling the LVDT was chosen as a reasonable compromise between the above specifications. With one hundred readings, a value was obtained for every 0.05 seconds during the 5 seconds. Based upon the graphs of

feedroll displacement versus time (Mains 1983), these one hundred readings should have detected any fluctuations in the feedroll displacement, and in addition, would have averaged and eliminated errors due to minor fluctuations in the signal voltage from the signal conditioner.

Each of the remaining transducer input lines was then sampled twenty times, and the readings averaged to eliminate minor signal voltage fluctuation errors. The differential ground voltage was subtracted from all of the readings. The required chemical flow rate was calculated, based upon the LVDT displacement and a calibration value (feed rate per LVDT displacement) which was calculated in the previous loop, and the corresponding optimal arrangement of nozzles was chosen. The digital word which would activate the proper solenoids was then sent on the output lines, and an updated calibration value for the next loop was calculated based on the equation:

$$a = w / (v \cdot t) \quad \ldots\ldots \quad 3.1a$$

where a = calibration value $(t/(h \cdot mv))$

w = cumulative mass of forage harvested (t)

v = current average of all the LVDT readings taken during this run (mv)

t = time since the start of the run (h).

Several additional variables (ie. actual chemical application rate, forage mass harvested during the previous loop) were also calculated (Appendix C). The transducer readings and calculated variables were then copied to a

printer, and program execution returned to the beginning of the loop.

The program could also run when the load cells from the forage wagon were not connected into the system, or were not being used to calculate the calibration value. In these cases, a calibration value from a previous run was entered via the minicomputer keyboard and used for the entire run. This feature allowed a second non-instrumented forage wagon to be used during harvest, while retaining the minicomputer operation for chemical application control.

3.2 RESULTS

3.2.1 SYSTEM ANALYSIS - APPLICATION RATE AND LINE PRESSURE

The harvest runs on the private farms (system runs) were to examine the operation of the modified application system, and ranged from 96 to 586 seconds in length, the time required to fill a forage wagon. The data (Appendix D) were collected on the minicomputer printer only, at 13 to 14 second intervals. The crops harvested were barley and a barley-oats mixture. The range of moisture contents (as measured with a CENCO moisture balance) was quite narrow (52% to 66%, wet basis), and one length of cut was used for the majority of the runs.

The application rates of sulphur dioxide to forage for each of these runs are recorded in Table 3.1. The chemical application control for each run was based on one of two

Table 3.1 Harvest variables and the chemical application rates for the system runs (preliminary study).

Run #	crop	length of run (s)	length of cut (mm)	"A1" value (t/hr/mv) calc.	used	applic. rate (%)
1	*1	448	19	0.356	-----	0.40
2		504	6	0.235	-----	0.33
3		112	6	0.208	-----	0.28
4		504	6	-----	0.235	0.44
5	*2	574	6	0.206	-----	0.44
6		602	6	-----	0.205	0.47
7	*3	532	6	0.242	-----	0.34
8		574	6	-----	0.240	0.39
9		574	6	-----	0.240	0.46
10	*4	518	6	0.215	-----	0.30

crop : *1 = Farm #1, day 1, 40% d.m. content barley.
*2 = Farm #1, day 2, 48% d.m. content barley.
*3 = Farm #2, day 3, 40% d.m. content barley/oats.
*4 = Farm #3, day 4, 34% d.m. content barley.

possible calibration values. The first run with each crop had to calculate the calibration value for that particular crop; therefore, these runs used a calibration value which was being continuously updated (Table 3.1, "A1 calc."). Later runs with a similar crop could use the calibration value which had been calculated in a previous run ("A1 used"). The specified chemical application rate was 0.35% (wet weight basis), and the rate actually applied during the runs using continuously updated calibration values ranged from 0.27% to 0.44% (mean=0.35%). The runs using a constant previously-calculated calibration value had application rates ranging from 0.39% to 0.47% (mean=0.44%), with an average deviation of 25% from the specified rate.

The equation used by the minicomputer program for calculating the feed rate during the trials was:

$$f = b \cdot y \qquad \text{3.1b}$$

where f = forage feed rate (t/h)

b = calibration value (t/(h·cm))

y = feedroll displacement (cm).

The value of b was calculated during each run, and was not necessarily constant over several runs having similar crops at the same moisture content and length of cut. This equation is not the one which would be used in a microprocessor-controlled chemical application system, and subsequently, the application control was not as accurate as it would be with the microprocessor-controlled system. The equation which would be used in a microprocessor-controlled

system could not be calculated until the calibration of the forage feed rate to the feedroll displacement had been completed, and these system trials were done prior to the calibration trials.

Additional inaccuracy was introduced into the application control system since the minicomputer only sampled the LVDT reading during a 5 second interval during each program cycle. An improvement in the accuracy of the application rate should be evident in a system which uses the calibration, and which measures the feedroll displacement continuously.

The variation of the pressure in the chemical lines during a typical system run can be seen in Figure 3.6. The pressure fluctuated between 360 and 640 kPa, with an average pressure of approximately 550 kPa, during run #6. The fluctuations in line pressure appear to be related to the chemical flowrate. A large drop in pressure corresponded to one of the larger nozzles being switched on. A pump was located between the chemical tanks and the solenoids, and a back pressure regulating valve regulated the pressure. However, the valve would not be able to instantaneously respond to a drop in line pressure when a larger nozzle switched on, or to an increase in line pressure when a smaller nozzle was activated. The fluctuations in line pressure probably were due to the response time of the valve, which appears to be several seconds. These fluctuations in pressure, which were a result of a changing

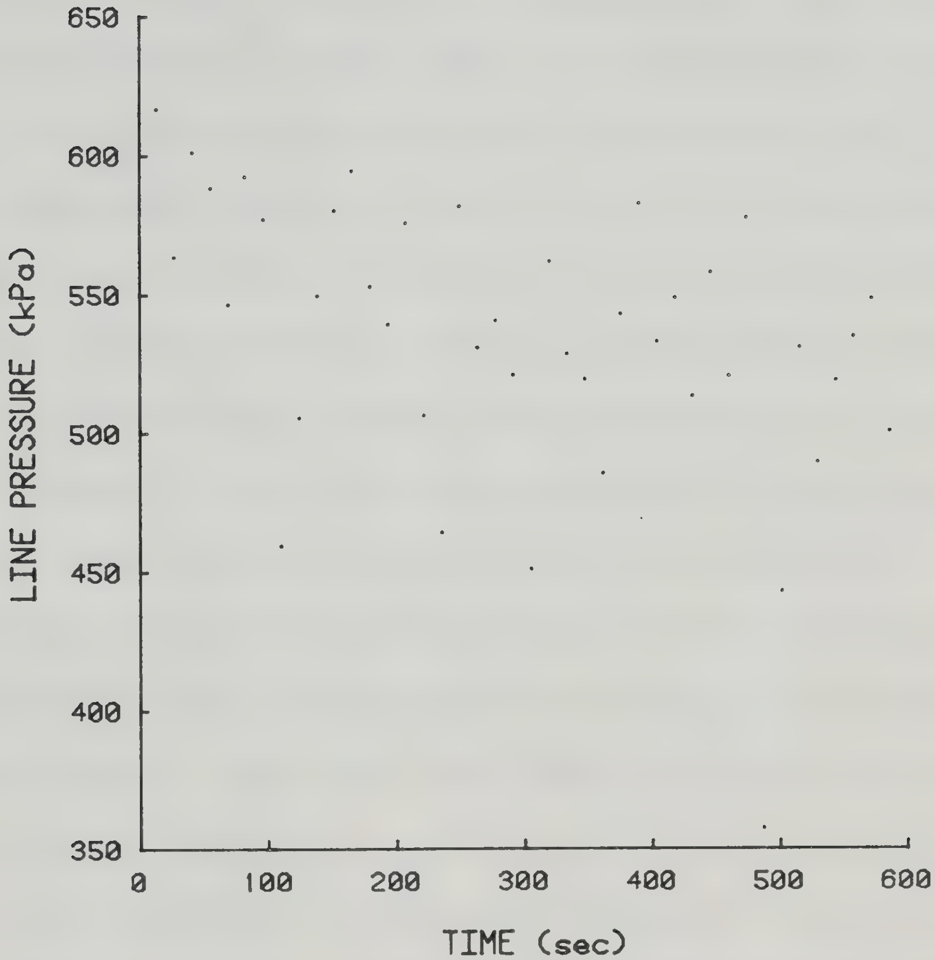

Figure 3.6 System run #6, pressure in the chemical line versus time.

chemical flowrate, and which in turn affected the flowrate, were taken into account in the design of the microprocessor-controlled chemical application system.

3.2.2 CALIBRATION - FEED RATE AND FEEDROLL DISPLACEMENT

The harvest runs done at the Ellerslie Research Station were to calibrate the feedroll displacement. The length of the trials ranged from 55 to 286 seconds, with the data being collected on paper tape at half second intervals. A range of crop moisture contents, lengths of cut, and forage feed rates were used in these trials. The crop moisture content was varied by allowing the crop to dry for different lengths of time between cutting and chopping. The length of cut was varied by a simple gear adjustment on the harvester, and a range of feed rates was obtained by varying the tractor speed and by raking crop rows together.

The average forage feed rate and the average feedroll displacement were determined for each calibration run. The average forage feed rate was found by fitting a straight line through the data on a graph with forage mass in the wagon as a function of time. The slope of this line is the feed rate. Figures 3.7 and 3.8 are representative of the data collected (Appendix E). It can be seen that the feed rates remained constant during each run. The feedroll displacement measurements taken during each run were averaged to give the average feedroll displacement over the entire run.

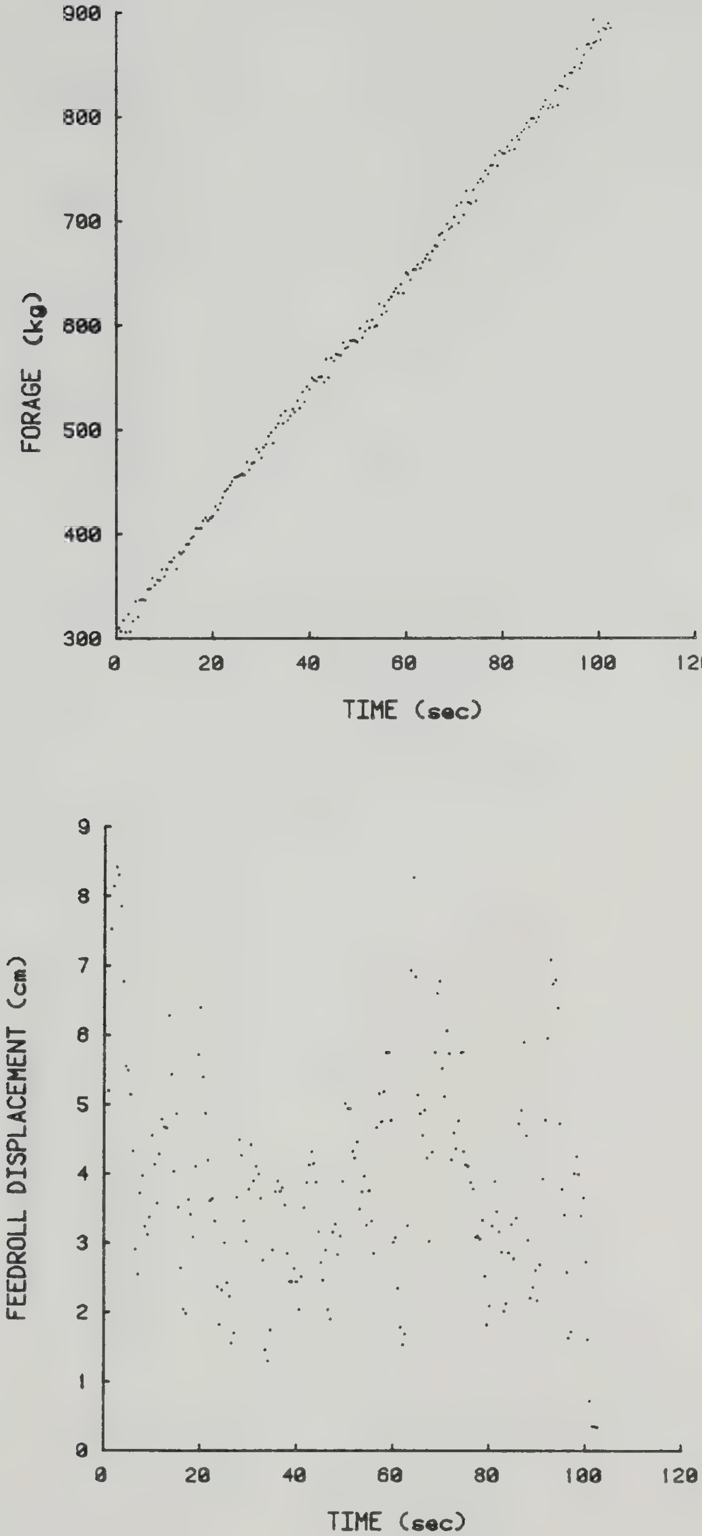

Figure 3.7 Calibration run #9 with barley; mass of forage in the forage wagon and feedroll displacement versus time.

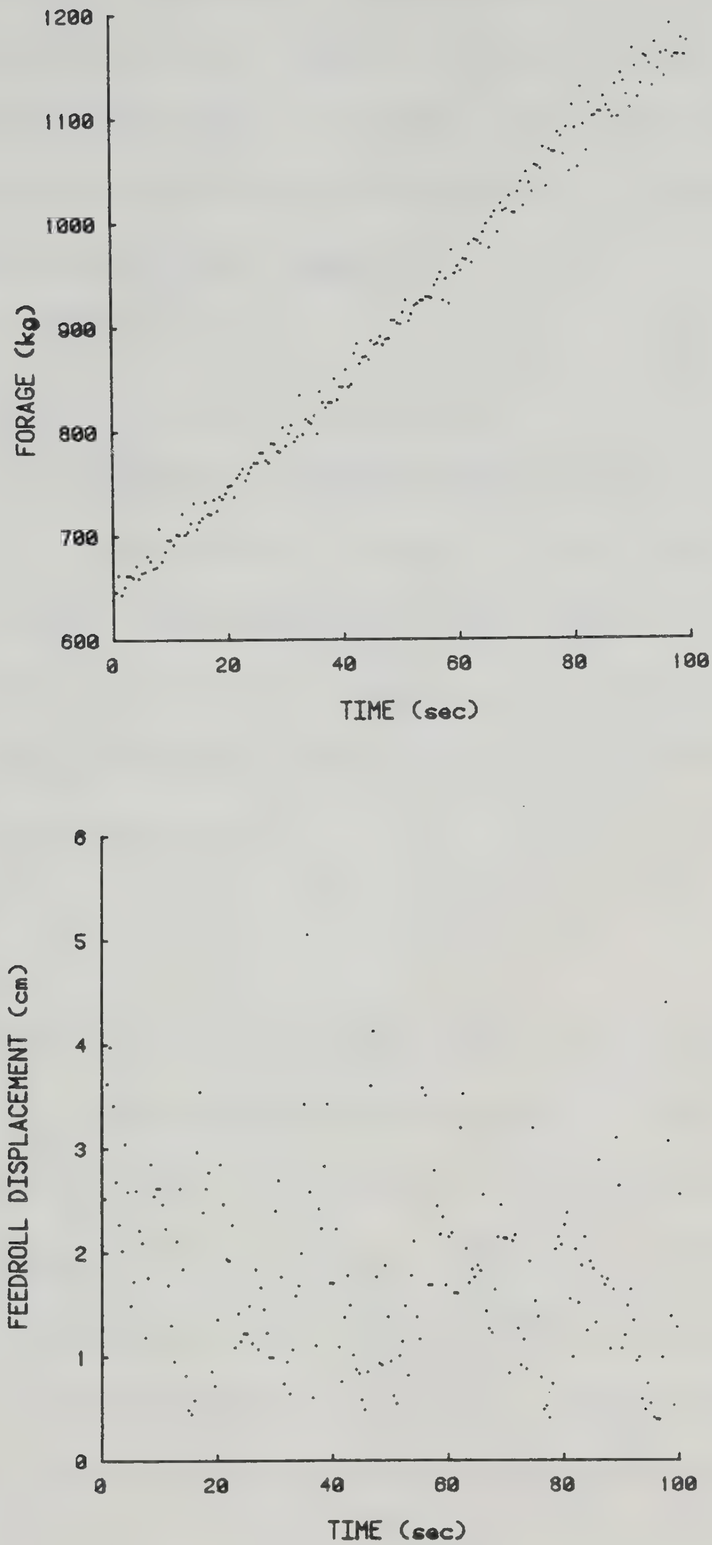

Figure 3.8 Calibration run #9 with alfalfa; mass of forage in the forage wagon and feedroll displacement versus time.

The relationship between two variables can usually be expressed by a polynomial, exponential, or logarithmic equation (Harrison 1973, Steel & Torrie 1960). Using a multiple linear regression program, the data collected at Ellerslie was fitted to these equations, and was found to best fit the logarithmic equation:

$$f = a + b \cdot \log(y \cdot l) \qquad 3.2$$

where f = forage feed rate (t/h)

y = feedroll displacement (cm)

l = theoretical length of cut (mm)

a,b = constants for each crop.

The fifteen data points for barley fit this equation with a R-squared value (coefficient of multiple determination) of 0.7773 and constants of:

a = 3.89

b = 5.85.

The coefficient of multiple determination is the proportion of variance in the dependent variable (in this case, f) accounted for by the relationship of it with the independent variables (Steel & Torrie 1960). Values of R-squared range from 0 to 1, with a perfect fit of data to an equation resulting in an R-squared value of 1. The R-squared value for the nine alfalfa data points was 0.4895, with constants of: a = 8.73

b = 3.69.

Graphs of the data points, and the best-fit equation can be seen in Figures 3.9 and 3.10.

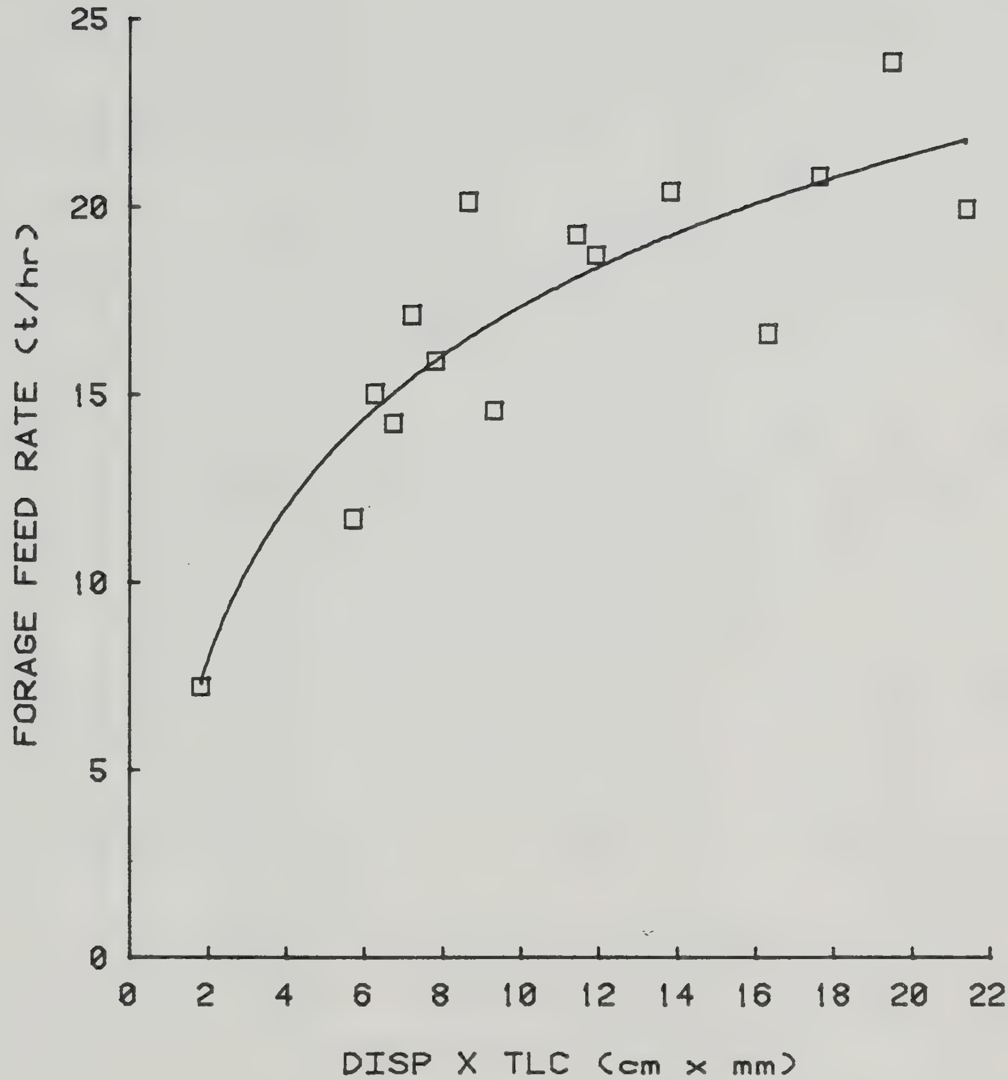

Figure 3.9 The relationship between the forage feed rate and the product of the feedroll displacement and the theoretical length of cut - barley.

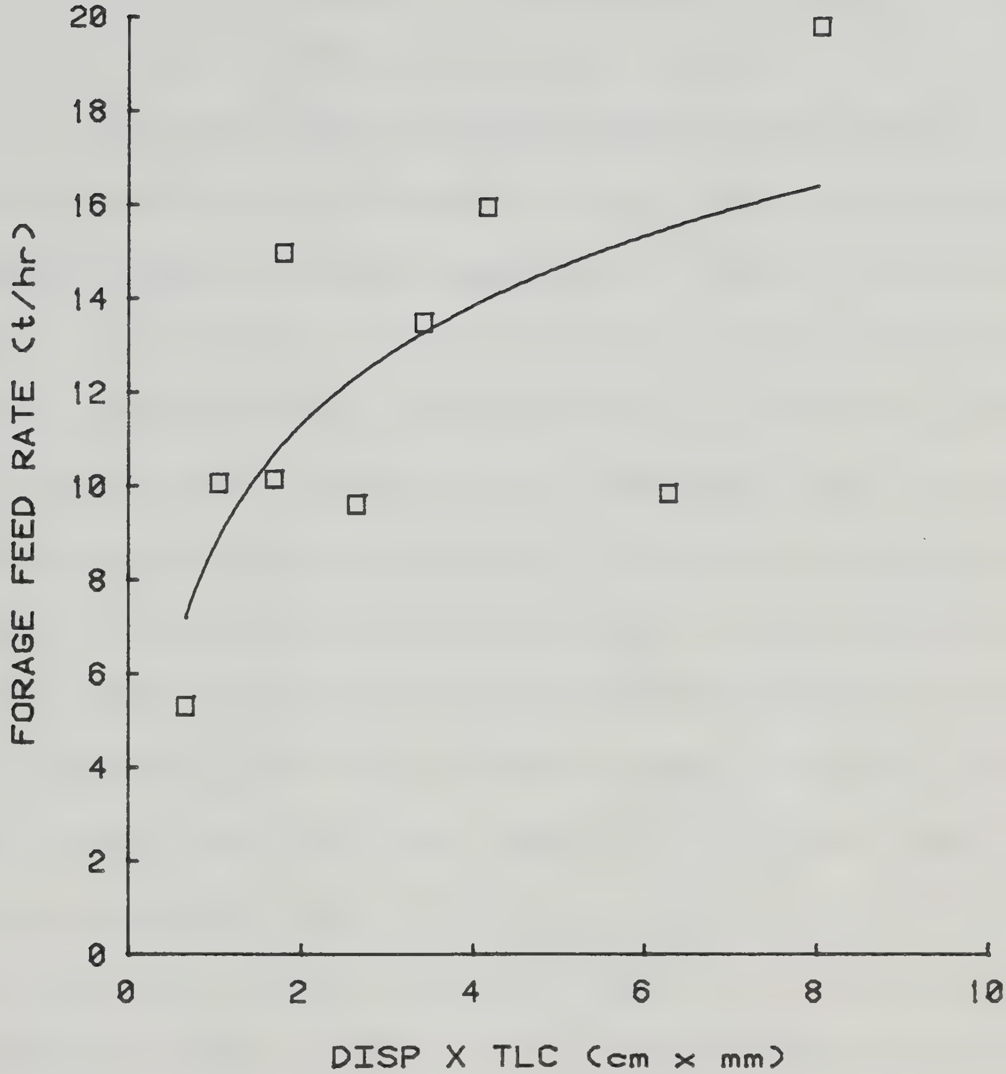

Figure 3.10 The relationship between the forage feed rate and the product of the feedroll displacement and the theoretical length of cut - alfalfa.

R-squared values of 0.5407 for the barley data and 0.3998 for the alfalfa data were obtained when the data was fitted to the linear (polynomial) equation:

$$f = a \cdot y \cdot l \qquad 3.3$$

where f = forage feed rate (t/h)

y = feedroll displacement (cm)

l = theoretical length of cut (mm)

a = constant for each crop.

It was noted that by deleting the data point for alfalfa at the 19 mm length of cut, the R-squared values increased to 0.7732 for equation 3.2 and to 0.5786 for equation 3.3. There is no justification for claiming this point to be "bad data" and deleting it. However, equations 3.2 and 3.3 are to approximate, not describe, the physical relationships between feed rate, feedroll displacement, and length of cut. Therefore, an extreme length of cut could yield a data point which is radically different from the data points at the less extreme length of cuts, and 19 mm is the longest (most extreme) length of cut available on the forage harvester used. Since it is unlikely that the 19 mm length of cut will be commonly used, the 19 mm data point could be deleted to allow the fitted equations to better approximate the feed rate at the lesser lengths of cut. The constants for the alfalfa data fitted to equation 3.2 when deleting this point are:

a = 8.38

b = 5.01.

The data point for barley at the 19 mm length of cut is not as different from the other data points as the alfalfa 19 mm data point is, possibly because of the different characteristics of the two crops.

Mains (1983) did not include the length of cut as a variable in his research; however, it has been included in equations 3.2 and 3.3. The length of cut on a forage harvester is varied by changing the ratio of the gear drive of the feedrolls, which changes the feedroll speed. The relationship between the feedroll displacement, feedroll speed, and theoretical length of cut can be expressed as :

(displacement) (1/speed)
and (speed) (length)
thus (displacement) (1/length).

Since the length of cut inversely influences the displacement, it was inserted into the equations as a multiplier of the displacement. Although the relationship between length of cut (feedroll speed) and displacement may not be an exact linear inversely proportional one, the results obtained with equation 3.2 are deemed adequate for this application.

The variable of dry matter content, which was included in the equations found by Mains (1983), was not included in equation 3.2 since it is unlikely that it would be known. Equation 3.2 should be reasonably accurate over the range of crop dry matter contents normally encountered during harvesting.

4. DESIGN AND TESTING

4.1 OBJECTIVE

The purpose of this study was to design an efficient and economical control system for applying a liquid chemical to forages, including such chemicals that are only in a liquid state at ambient temperatures if their pressure is greater than atmospheric. The system must be capable of measuring the forage feed rate through a harvester, and of controlling the chemical flowrate to give a specified chemical application rate with respect to forage mass. In addition to the control system, a monitoring system would be advantageous. The monitoring system would provide information, such as the forage feed rate and the total chemical used, to the operator. Either system could be used independently with a forage harvester, or both systems could be used together. With some modifications, either system might also be used with a baler.

4.2 MONITOR

The monitor from the ZT-4 driving computer package (ZEMCO, San Ramon, California) was used for the monitoring system to provide information to the operator. When used with an automobile, the vehicle distance travelled and the fuel usage are monitored. The monitor has an internal clock to give a readout of time and allow calculations of the vehicle speed and the fuel flowrate, and it is designed to

operate from an automobile battery (Zemco 1983).

The ZT-4 monitor was chosen for this application since its automobile measurements and calculations parallel those which are necessary in the monitor for this chemical application system. In addition, the ZT-4 computer package includes a flowmeter which could be modified for use with this system, and a magnetic detector which had the potential for use in a magnetic feed rate sensor.

The specifications and circuit diagram for the ZT-4 monitor were not available. The flowmeter was designed for use with this monitor; therefore, no intermediary circuit was necessary between the monitor and flowmeter. The circuitry necessary to allow connection of a feed rate sensor to the monitor is discussed in section 4.3.

4.3 FEED RATE SENSOR

During the calibration trials in the preliminary study, the forage feed rate was calibrated to an exponential function (equation 3.2) and a linear function (equation 3.3) of the product of the feedroll displacement and theoretical length of cut (or rotational velocity). A sensor capable of measuring this product, to be used in these equations, was required. The feedroll displacement was effectively measured with an LVDT during the preliminary study, and the rotational velocity could be easily measured with a dc tachometer. However, both of these transducers are analog devices, and are therefore not directly compatible with a

microprocessor, which accepts only digital information. With some signal conversion, the LVDT and tachometer could be used in a microprocessor system (Mitchell 1981); however, less expensive sensors with a digital output are available and more feasible.

The feed rate is calculated with the value of feedroll displacement times rotational velocity. The independent values of feedroll displacement and rotational velocity are not required; therefore, a single sensor could be used to measure their product. Three sensors were considered for use in measuring this product. Each of the feed rate sensors consisted of a patterned disk, and a corresponding detector located nearby. The disk was to be connected to an upper feedroll on the harvester, and rotate and displace with it.

The detectors examined for the feed rate sensor were a magnetic detector, a reflective object detector, and an infrared light emitter and detector. The disk used in each system would have a pattern of objects or holes to which the particular detector was sensitive. The location of the detector and the pattern would be such that the number of objects or holes detected, and therefore, the number of detector output signal pulses, is proportional to the displacement times velocity. Unlike the "encoded disks" discussed in the literature review, which sense rotational displacement or rotational velocity, these "patterned disks" would be used to sense the product of rotational velocity and linear displacement.

The circuit diagram for a sensor using magnetic detection of magnets on a disk, is shown in Figure 4.1. The magnetic detector can be wired directly into the monitor. The additional circuitry in this diagram is required for amplifying and conditioning the detector signal to make it compatible with the microprocessor control system. The magnets on the disk could be either long and narrow, aligned along the radii of the disk, or they could be smaller and located such that the number of magnets detected at any radius on the disk would be proportional to that radial distance.

The circuit for a sensor using a reflective object detector, is diagrammed in Figure 4.2. As with the magnets, reflective strips on the disk would be patterned such that the number of strips detected would be proportional to the radial distance. The reflective object detector would be aligned with the vertical axis of the disk.

Figure 4.3 shows the circuit diagram for the third sensor, with an infrared light emitter and an infrared light detector located on opposite sides of a disk. The disk could have slots, following a pattern similar to the one for the reflective strips and the long magnets, or an arrangement of holes in a pattern similar to the small round magnets. Each time a slot or hole passed between the emitter and the detector, the detector would sense the infrared light and put a "high" voltage on the output line. The emitter and detector would have to be offset from the disk center to

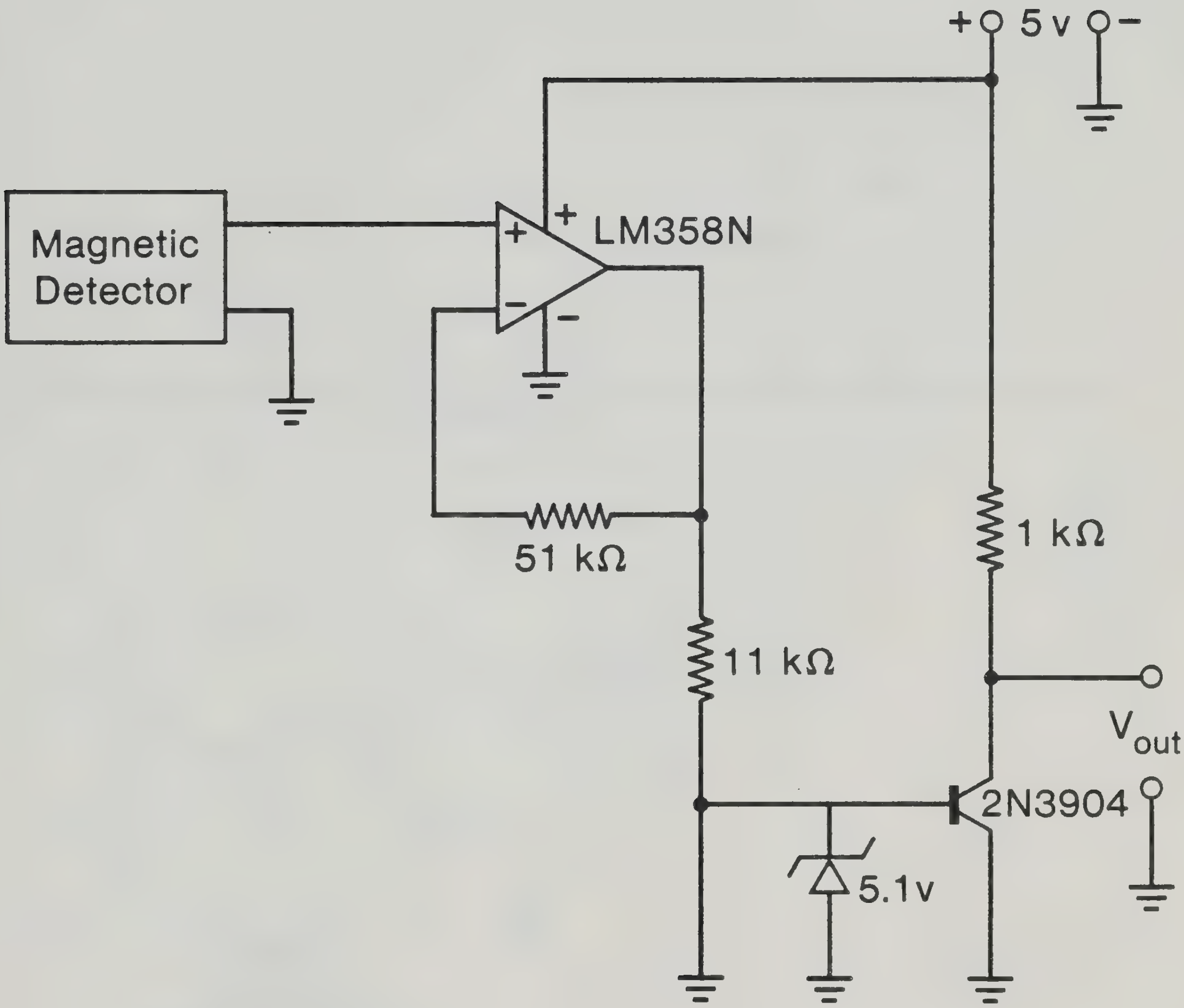

Figure 4.1 Circuit diagram for the magnetic detector.

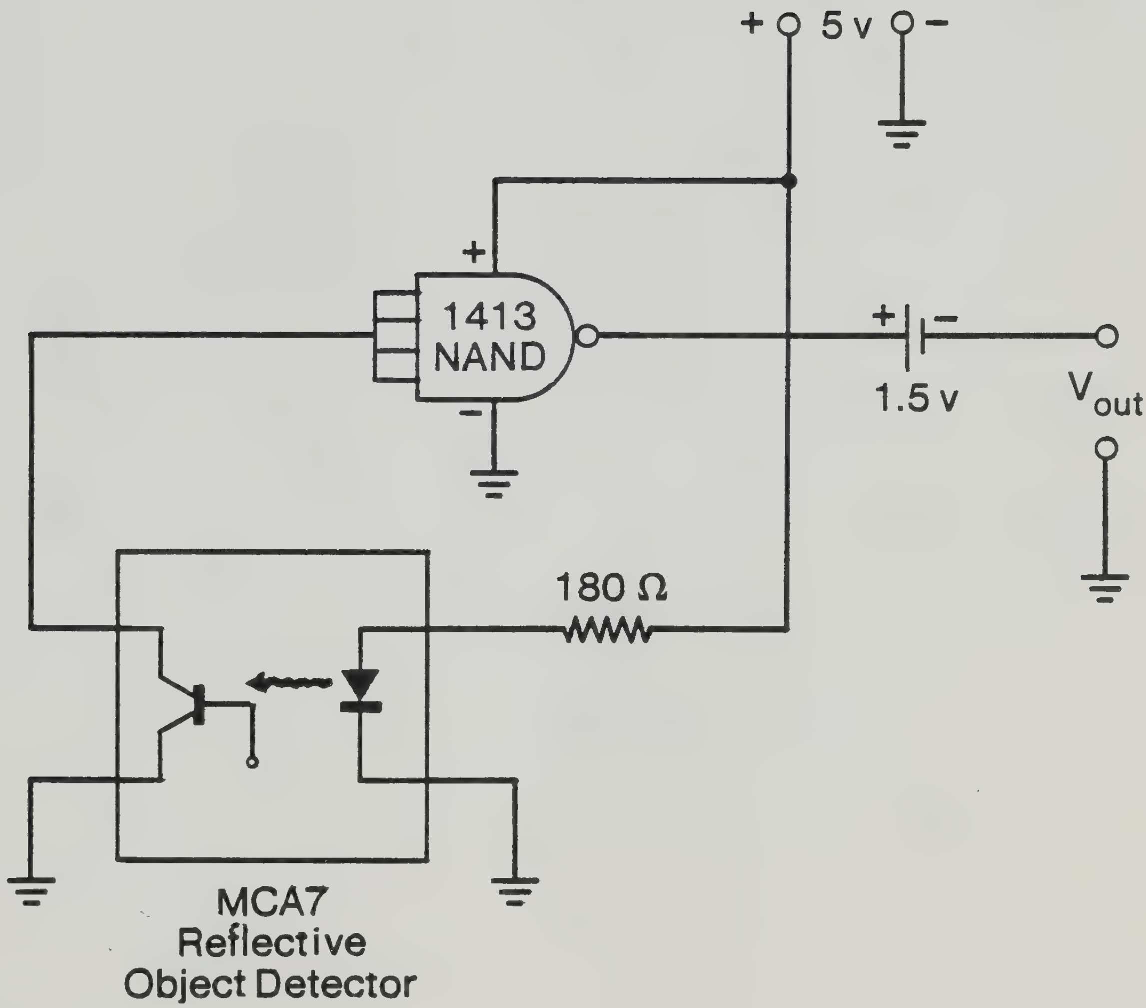

Figure 4.2 Circuit diagram for the reflective object detector.

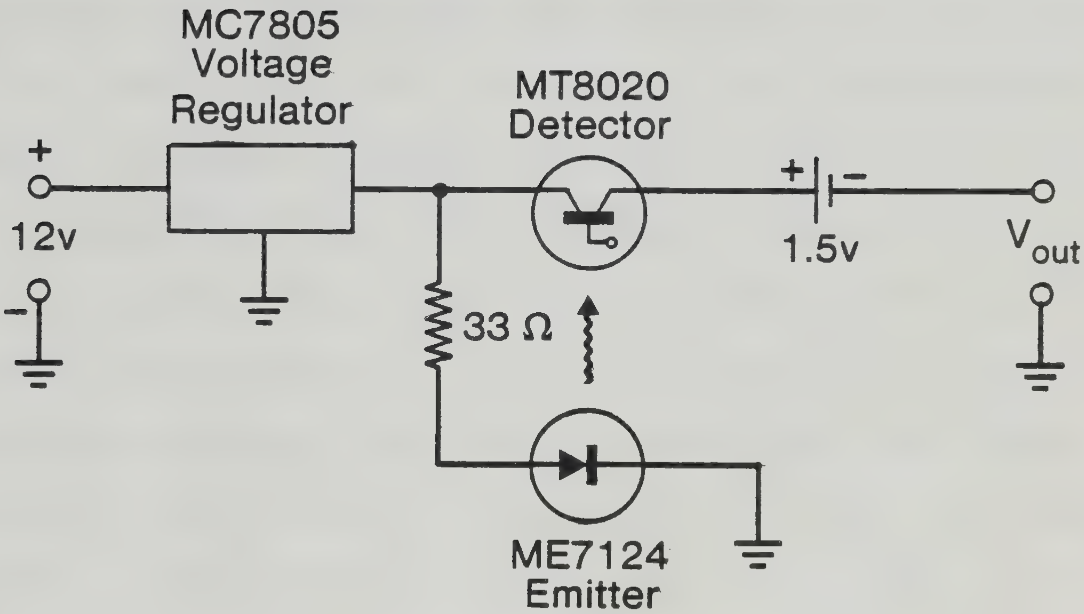

Figure 4.3 Circuit diagram for the infrared light emitter and detector.

allow for the shaft which fastens the disk to the feedroll.

Since the monitor was designed to interface with a magnetic detector on the input signal line being used by the feed rate sensor. The signal generated by the magnetic detector was therefore examined, and the feed rate sensor circuits were designed to output a signal compatible with the monitor. There are two signal lines from the magnetic detector to the monitor. The signal on one of these lines is a voltage pulse which goes from a "high" positive voltage to a "low" negative voltage. The second line is connected to ground. The monitor detects the pulse on the first line when the voltage drops below the voltage on the second line (ie. when the voltage drops below 0). Therefore, the feed rate sensors had to output a signal which went from a positive to a negative voltage, relative to the monitor. The single cell battery in the circuits in Figures 4.2 and 4.3 was used to drop the output of 0 to 5 volts down to an output of -1.5 to 3.5 volts. Prior to installing the battery, attempts were made to input a small positive voltage on the second line to be used as the threshold voltage at which the pulse was detected; however, the second line is grounded inside the monitor, and consequently, this alternative did not work.

The magnetic and reflective object feed rate sensors were briefly examined. The magnetic feed rate sensor was not built since the fewer number of problems associated with the infrared light emitter and detector made that sensor more feasible. The circuit for the magnetic sensor is more

complex than the emitter and detector circuit, and the distinction between an "on" and an "off" voltage from the magnetic detector is questionable. The magnetic detector signal is analog, with the magnitude being dependent on the magnetic field induced. This magnetic field varies with the strength of the magnets, the distance between the magnet and the detector, and the velocity of the magnet; therefore, the choice of a cutoff voltage to distinguish between a digital signal "on" and "off" is arbitrary and the sensor would have to be calibrated for each disk and each feedroll speed or length of cut.

The feed rate sensor utilizing a reflective object detector was built and found not to be feasible. Strips of reflective tape, such as that used on bicycles and automobiles, were placed on a disk. To respond to the reflective strips, the detector had to be parallel to the axis of disk rotation; however, the axis of the feedroll can tilt. In addition, the reflective strips were not detected at a distance of more than 1 cm from this detector, and with some forage harvesters, a clearance of at least 1 cm would be necessary to allow for the tilt on the feedroll axis. The reflective object detector was also very sensitive to ambient light and would require a shield to block out most of the direct and diffuse ambient light. A feed rate sensor using a reflective object detector might be feasible with a more powerful detector, more reflective and multi-directional strips, and a shield.

The feed rate sensor using the infrared light emitter and detector was more thoroughly tested. Tests were done with the light emitter and detector and several disk patterns (Figure 4.4). Since the maximum feedroll displacement measured with the Hesston 7150 forage harvester during the preliminary study was approximately 10 cm, a radius of 12.7 cm (5 in) was used for the disks. During the preliminary study, it was also found that the choice of the optimal nozzle to be turned on could be dependent on a feedroll displacement as little as 1 cm. Therefore, the disks designed required a sensitivity of at least 1 cm of displacement.

Perforated round-hole screen disks were tested, as well as a disk with a unique pattern of holes, and disks with slots. The disks made with the perforated round-hole screens (Figures 4.4a, b, c) had hole diameters of 0.79, 1.27, and 2.54 cm (0.3125, 0.5, and 1.0 in). The spacing between any two adjacent holes on one of these disks was the radius of a hole.

The unique hole disk (Figure 4.4d) had 2.2 cm (0.875 in) diameter holes, which were located at 1 cm radius increments. This allowed a slight overlap between the holes in adjacent 2 cm width rings. For any integer "X" between 0 and 12, the number of holes detected at any radial displacement between "X-0.5" and "X+0.5" cm was "X". This pattern provided a displacement sensitivity of 1 cm. The two slotted disks examined had displacement sensitivites of 1 cm

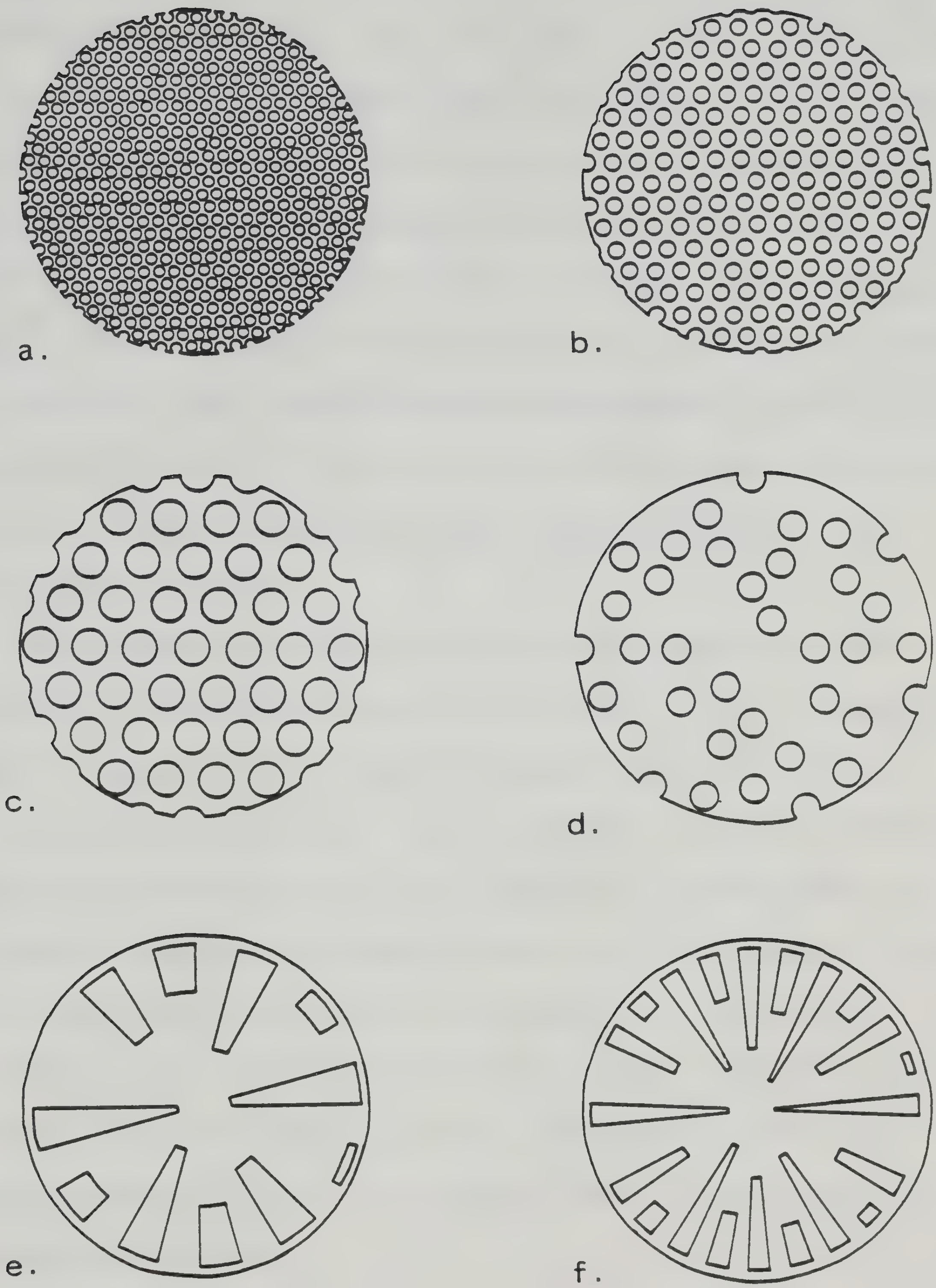

Figure 4.4 Disk patterns tested with the infrared light emitter and detector : (a) small, (b) medium, and (c) large round-hole screen; (d) unique hole; (e) 11-slot; and (f) 21-slot.

and 0.5 cm. These patterns (and the corresponding sensor) were offset from the disk center by 1 cm to allow space for the shaft of the disk. The locations of the holes or slots on the disks gave a maximum spacing between holes or slots at the same radial distance. This spacing resulted in a sensor output signal frequency which is as uniform as possible, reducing the incidence of high frequencies which might exceed the limits of the control or monitor system, and allowing the controlling microprocessor program to run more efficiently. In addition, this even spacing allowed accurate displacement readings when the feedroll had a varying displacement.

The disks were mounted on a drill press for test purposes, and the disk was rotated at 120 rpm, a typical feedroll speed. The detector output signal line was connected to the monitor and to a pulse counter. Output signal counts were then taken with the emitter/detector located at several distances from the disk center. These runs tested for "dead spots" in the disk, poor hole patterns, and holes which were too close together to be read individually. In addition, the runs checked that the monitor could successfully read the signal being generated with the designed circuitry.

4.4 CHEMICAL FLOW SENSOR

The flowmeter used was supplied with the monitor and is designed for measuring the fuel consumption in a vehicle. This flowmeter uses an optoelectronic sensor to measure the flowrate. A light emitter and a detector are located on opposite sides of a raceway channel in the flowmeter. As liquid flows through the raceway, a small ball in the channel is displaced and travels around the raceway, interrupting the light beam between the emitter and detector. The frequency of these interruptions, and of the subsequent detector output signal, is proportional to the liquid flow rate.

The flowmeter was modified by replacing the rubber seals and components, which were susceptible to attack by sulphur dioxide, with teflon parts. The modified flowmeter was calibrated with water in the range of flowrates which would be used in a field application with the chemical, sulphur dioxide. This range was from 0.28 to 1.84 L/min, based upon a chemical application rate of 0.35% (wet weight) and a forage feed rate ranging from 9 to 45 t/h. The output signal from the flowmeter was connected to the monitor and to a pulse counter, and a measured amount of water was passed through the flowmeter. The pulse counter and monitor readings were compared to determine whether any signals might have been missed by the monitor due to flowrate limitations or other problems in the monitor.

4.5 APPLICATOR NOZZLES

The solenoid valves for the nozzles were controlled by the microprocessor. Since the microcomputer was incapable of outputting sufficient current to energize the solenoid, an intermediary circuit was required to boost the control signal. The intermediary circuit used was the same as the circuit located between the minicomputer and the solenoids in the preliminary study (Appendix B). It was anticipated that the system would use four applicator nozzles of the same capacities as used in the preliminary study, for the same reasons; however, more or fewer nozzles, or nozzles of different capacities, could be accomodated.

4.6 MICROPROCESSOR CONTROLLER

A microcomputer system which could respond to the signals from the feed rate sensor and the flowmeter, and produce the optimal chemical flowrate, was required. In addition, the microcomputer system had to be easy to calibrate since the system must be calibrated to the type of crop being harvested and the required chemical application rate. The microcomputer should be designed to run from the 12 volt tractor power supply, and the microcomputer components should be readily available, inexpensive, and rugged.

The Motorola 6802 microprocessor was chosen. The 6802 incorporates the 6800 microprocessor with an on-chip clock oscillator and 128 bytes of RAM (random access memory). This

eliminates the need for these two additional chips in the microcomputer system. The 6800 is an 8-bit microprocessor, and is capable of addressing 64K bytes of memory. The 8-bit data bus is multidirectional. These features allow the 6802 microprocessor the capabilities required in this application, yet the 6802 is still simple and small enough to be practical. Similar microprocessors are available from other companies, such as the Zilog Z-80 and the Intel 8080 series. These microprocessors have the same capabilities as the M6800, but the M6800 was chosen because of its availability and greater popularity (Motorola 1981, Page et al. 1977, Craig 1982, Hinkle 1982). The 6820 PIA (peripheral interface adapter) for I/O (input/output) operations, and the MCM2716 EPROM (erasable programmable read only memory) for program storage were selected. The MCM2716 memory is permanent in the event of power failures or shutdowns; however, the program and permanent data can be stored (written) into memory by an individual system designer and need not be mass produced at the factory. This feature makes the MC2716 EPROM economical and feasible for non-mass production systems, and permits the designer to erase and rewrite into the memory, thereby making future modifications to programs possible. A voltage regulator allows the microcomputer to run from the tractor battery, and a crystal circuit provides the input to the on-chip clock. All of these components met the requirement of being inexpensive, rugged, and readily available. (Craig 1982, Greenfield 1981,

Motorola 1981, Hinkle 1982, Page 1977).

The circuit diagram for such a microcomputer system can be seen in Figure 4.5 (Craig 1982). The operator calibrates the system by setting a series of eight "on/off" switches. Four of these switches indicate the required chemical application rate. The remaining four switches are set according to the type of crop being harvested and harvester being used. The microprocessor has several sets of feedroll equation constants in its memory, and it would retrieve the most appropriate set of constants for the type of harvest run specified by these four switches. These switches are connected to eight of the sixteen I/O lines of the PIA. The feed rate sensor is connected to one of four "interrupt" lines on the PIA. On a voltage pulse from the feed rate sensor, a count of these pulses would be incremented. The flowmeter is similarly connected to another of the "interrupt" lines. Four of the remaining eight PIA I/O lines are used to output the signal from the microcomputer to the power amplifier which switches the solenoids. The four remaining PIA I/O lines remain unused in this system, but could be connected to additional solenoid valves, indicator lights (ie. extreme feed rate conditions), or additional monitoring transducers.

When the microcomputer system is powered on, the microprocessor would begin execution of the program to control the application of a chemical to a forage. A listing of this program is recorded in Appendix F. Upon start-up,

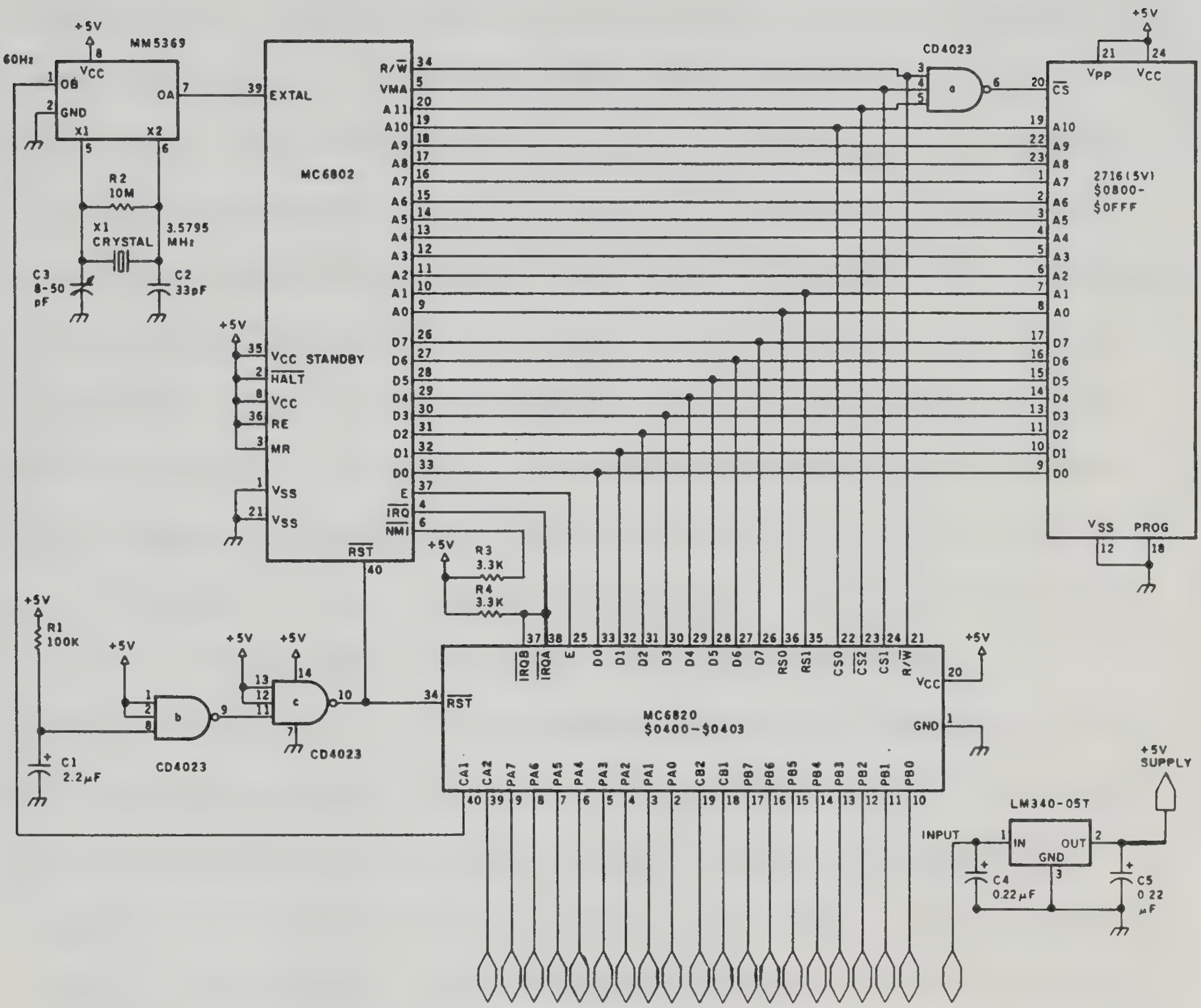

Figure 4.5 Circuit diagram of the microcomputer control system (Craig 1982).

the program samples the switches set by the operator and stores the resulting value. The program then enters a continuous loop which is interrupted only by the feed rate sensor or flowmeter signals. Each time there is an "interrupt", the microprocessor jumps to a subroutine which determines which sensor has sent the pulse and then increments the pulse count for that sensor. Every second, the microprocessor reads the feed rate sensor count and calculates the forage feed rate over the previous second and the required chemical flow rate for this feed rate, based upon equation 3.2 and the value initially entered on the switches by the operator. The microprocessor then chooses the nozzle or nozzle combinations which will give a flow rate nearest to the required flow rate, and instructs the PIA to activate the corresponding solenoids. The microprocessor then calculates the chemical flow rate from the flowmeter count over the previous second. If the flow rate measured differs significantly from the expected capacity of the active nozzle(s), then the nozzle capacity value is updated to the measured flow rate value, for use during the remainder of the run.

5. DESIGN RESULTS AND DISCUSSION

5.1 MONITOR

In the chemical application system designed, a ZT-4 driving computer was used as the monitor which provided a readout of the forage harvested, based upon a signal input from an optoelectronic sensor, and the chemical used, based upon a signal input from a flowmeter. The monitor also calculated and provided a readout of the forage feed rate, chemical usage rate, and the forage weight harvested per chemical weight applied.

The monitor calculates the forage weight based upon equation 3.3, the linear relationship between the feed rate and the feedroll displacement times rotational velocity. As can be seen from the R-squared values in section 3.2.2, the linear equation does not yield as accurate estimates of the dependent variable as the logarithmic equation. The monitor (ZT-4 driving computer) is permanently programmed with a linear relationship for its original intended use of measuring the distance travelled by a vehicle, and the convenience and low cost of the driving computer package justify the use of ZT-4 monitor, despite the less accurate estimates.

The monitor was used in tests with both the feed rate sensor and the modified flowmeter. Reliable readouts (as verified with a pulse counter) were obtained with the unique hole and slotted disks in the feed rate sensing system and

with the flowmeter. The tests were done with the range of feed rate sensor signals and flowmeter signals which would be encountered normally.

5.2 FEED RATE SENSOR

The feed rate sensor with the best potential was judged to be the one with the infrared light emitter and detector. A schematic of the light emitter and detector and the disk can be seen in Figure 5.1. The emitter and detector could be placed up to 5 cm apart. The circuit did not detect ambient light except when the detector was placed in direct sunlight on a bright day, and the design (Figure 5.1) blocked enough sunlight to prevent this. The signal from the circuit can be read by the monitor, and should be compatible with the microcomputer controller as well.

Of the six disks tested with the infrared light emitter and detector system, the slotted disks were the most effective for measuring the product of feedroll displacement and rotational velocity (Appendix G). With the disks made from perforated round-hole screen, a limitation was encountered with the monitor with regard to the frequency or pulse width of the signal. The monitor was unable to respond accurately to the signal at the larger radial distances on the small and medium round-hole screens of 0.79 and 1.27 cm hole diameter. It responded to the signals at any radius on the large (2.54 cm diameter) round-hole screen only. Furthermore, the round-hole screen disks did not have a

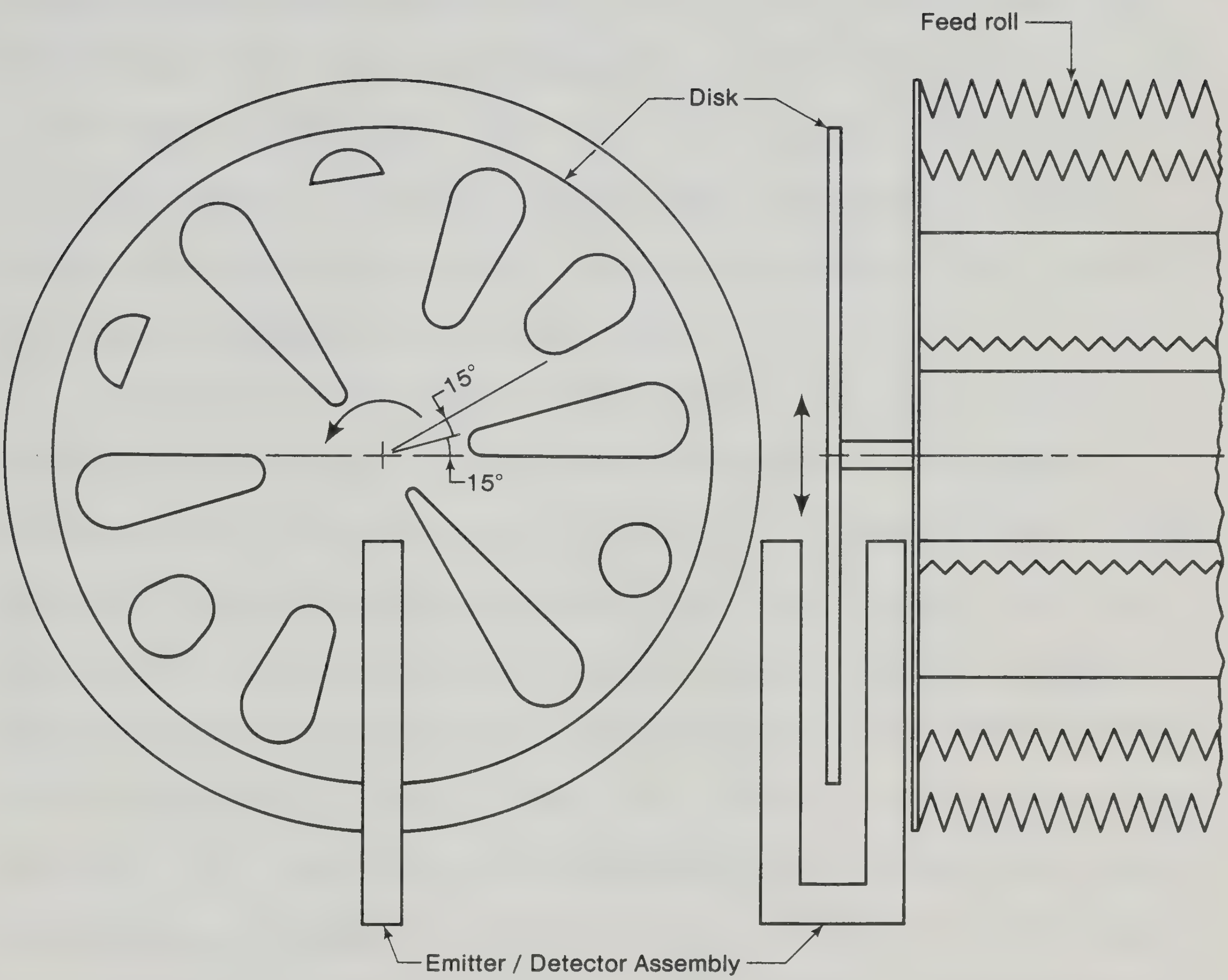

Figure 5.1 Feed rate sensor utilizing the infrared light emitter and detector, and the 11-slot disk.

satisfactory pattern of holes. The number of holes was not proportional to the radial distance, particularly for the large round-hole screen.

The unique hole disk effectively indicated the displacement with a sensitivity of 1 cm; however, it would not be reasonable to make a similar disk with a greater sensitivity. The manufacture of such a disk would be time-consuming and impractical due to the large number of holes required, and the complexity of the hole pattern. Such a disk would also have smaller holes, and it is probable that the monitor limitation on signal frequency or pulse width, encountered with the round-hole screen disks, would also be encountered with this disk.

The two slotted disks with the emitter and detector system proved to be an effective indicator of feedroll displacement times velocity. The output signal at any radial distance on the disks was compatible with the monitor, and the signal output was proportional to the radial distance. The highest signal frequency measured by the monitor in the drill tests, with the 21-slot disk (Figure 4.4f) at a radial distance of 11 cm (20 slots detected), was 40 Hz. The upper feedrolls on forage harvesters have rotational velocities between 60 and 200 rpm; however, the feedroll displacement would be lower at the higher velocities. Therefore, a signal frequency greater than 40 Hz should not be normally encountered.

5.3 CHEMICAL FLOW SENSOR

The pulse counter and monitor readout values for the calibration done on the flowmeter are recorded in Appendix H. The flowrates used in this application are higher than the fuel flowrates ordinarily measured by the monitor; however, the flowmeter and monitor functioned efficiently at these higher flowrates and the flowmeter could be successfully calibrated.

5.4 MICROPROCESSOR CONTROL SYSTEM

The complete microprocessor-controlled and monitored chemical application system is diagrammed in Figure 5.2. The flowmeter and feed rate sensor are inputs to the microcomputer system which controls the solenoids of the applicator nozzles. The solenoids are activated based on a calibration value set by the operator, as well as the forage feed rate and the flow rate. The feed rate sensor and flowmeter are also connected to a monitor (the ZT-4 driving computer) which independently provides information on the system to the operator.

The accuracy of the control system is limited by the accuracy of equation 3.2, relating the product of feedroll displacement and velocity to the feed rate, and the available flow rate settings of the nozzles. The number of nozzles, and their capacities, could be changed with little change to the microprocessor program. Four nozzles with flow rates of 0.38, 0.57, 0.76 and 1.14 L/min provide an adequate

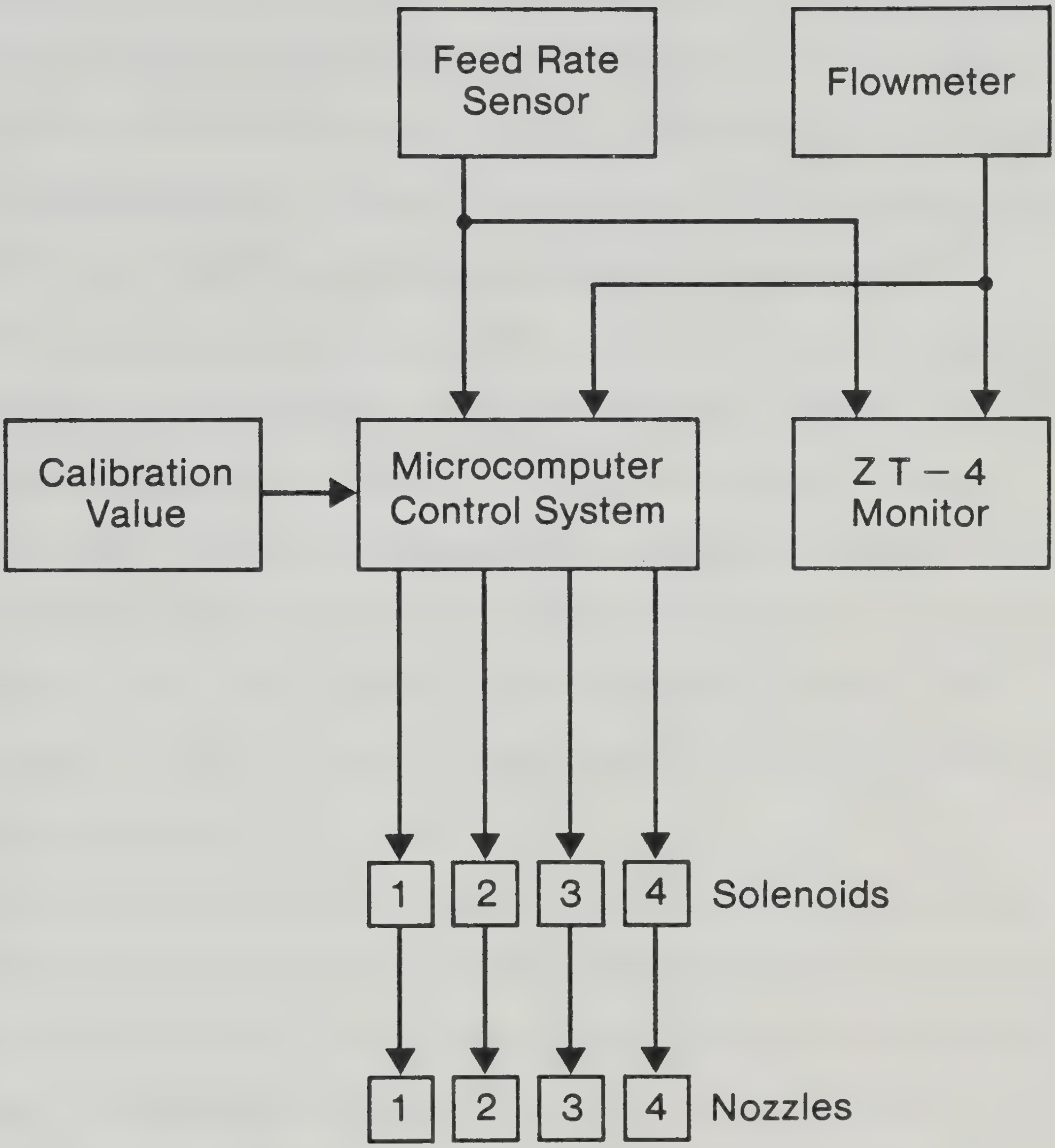

Figure 5.2 Block diagram of the microprocessor-controlled and monitored chemical application system.

range for treating forage with sulphur dioxide at the application rate of 0.35% of the wet matter (1% of the dry matter).

The controller and the monitor will have to be calibrated for each forage harvester. Furthermore, the springs on the feedrolls may be adjusted, so that the calibration for a forage harvester may be rendered useless by an adjustment to the spring tension. Calibrations would required for each crop to be harvested (ie. barley, alfalfa). In the present system, several sets of calibration constants are stored in the microcomputer memory and the operator specifies the set of constants to be used by setting four switches. This control system could be modified to allow the operator to calibrate his particular forage harvester and crop, rather than choosing the set of constants for the harvest conditions which most closely resemble his own.

The control system could function with a pressure transducer in the chemical line, rather than a flowmeter. This would involve a modification to the microprocessor program in which the flowrate for a nozzle would be calculated from the measured pressure, rather than being measured directly. Since a pressure transducer has an analog output and the control system uses digital signals only, it would be necessary to add an analog to digital converter to the microcomputer system. With such a control system, the accuracy would be further limited by the equation relating

the nozzle flowrate to the line pressure, and the inability of the system to know whether a nozzle was partially or wholly blocked. Furthermore, the monitoring system would not function with the pressure transducer unless the control system calculated the flow rate and sent the appropriate signal to the monitor. With a pressure transducer rather than a flowmeter, the monitoring system could no longer be independent of the control system.

Since the system monitor and the controller are two separate entities, it is possible to use one or the other or both. The microprocessor controller could calculate and output the system information on a display. The addition of a monitor into the control system would be simple in the microprocessor program. However, this would eliminate the option of using the monitor only, and sufficient I/O lines to accomodate such a display are not available in the present microcomputer system. An additional PIA would have to be added, along with a display. In addition, a flowmeter as suitable as the one provided with the ZT-4 driving computer would have to be found and purchased. The ZT-4 monitor was therefore considered to be the most versatile and feasible monitoring option.

6. CONCLUSIONS

A sensor to measure the forage feed rate through a forage harvester with reasonable precision is feasible. The feed rate sensor developed measured the product of the feedroll displacement and rotational velocity to obtain a measure of the feed rate, independent of the length of cut.

An infrared light emitter and detector, and a slotted disk connected to the feedroll, were used to obtain the product of displacement and velocity. The optoelectronic sensor was judged to be more suitable than the magnetic sensor for this application.

A monitoring system, which used the developed feed rate and modified flow rate sensors, was capable of indicating the forage feed rate, cumulative weight of forage cut, chemical flow rate, cumulative weight of chemical used, and the application rate. The precision of such a system is limited by the inaccuracies of the feed rate and flow sensors; however, it is much more precise than visual estimates of the forage feed rate and of the flow rate of a chemical at varying pressures.

The microprocessor control of a liquid chemical application system, which is capable of controlling the application rate of the chemical to the forage using the developed feed rate and modified flow sensors, is also feasible. As with the monitor, the precision of the system is limited by the inaccuracies of the two sensors, and also by the capacities of the applicator nozzles being used;

however, this system would be far more precise than any manual control method.

7. RECOMMENDATIONS

Calibration values, to be employed by the control system, must be obtained for the crops and forage harvesters used. As an alternative to storing a set of calibration values for each unique harvest condition in the microcomputer memory, the operator could calibrate the system for his particular crop and forage harvester. This would require modifications to the control program and the installation of additional switches for input.

The microcomputer of the control system should be built and the control program should be run to test for program errors and interfacing problems between the microcomputer components.

The cost effectiveness of the control system could be determined by using a computer simulation program to model the operation of the microprocessor-controlled chemical application system and a manually controlled application system, and comparing the chemical used with the two systems.

The feed rate sensor might be adapted to measure the feed rate of hay during baling or grain during combining. A different sensor would be required for measurement of grain in an auger. The microprocessor-controlled chemical application and monitoring systems could then be used for hay as it is baled, or for grain as it is combined or elevated for storage.

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APPENDIX A

Calibration of the LVDT

The signal conditioner provided the excitation voltage and conditioned the output signal from the LVDT. The signal conditioner output was recorded for measured displacements over the entire range of the LVDT. The feedroll displacement is three times as large as the LVDT displacement because of the cantilever arrangement.

LVDT displacement (cm(in))	signal conditioner output (mv)
0.00	0
0.85 (0.33)	116
1.65 (0.65)	239
2.33 (0.92)	352
3.47 (1.37)	539
4.66 (1.83)	716
5.25 (2.07)	816
5.80 (2.28)	904
6.39 (2.52) - maximum	990

$$y_1 = 0.006464 \cdot z$$

$$y_2 = 0.1939 \cdot z$$

where y_1 = LVDT displacement (cm)
y_2 = feedroll displacement (cm)
z = signal conditioner output (mv)

Calibration of the Forage Wagon Load Cells

The four load cells were each wired into a signal conditioner channel. Each channel provided the excitation voltage and output signal conditioning for its load cell. The signal conditioner outputs were recorded for a known load on the front load cells and on the rear load cells. The load cells were calibrated in pairs since the weighting of only one corner resulted in reaction forces at all four load cells, whereas the weighting of one end of the wagon primarily influenced only the two load cells at that end.

mass (kg) on load cell #					output (mv) on channel #			
1	2	3	4		1	2	3	4
0	0	0	0		-3	10	7	-13
0	0	0	0		6	8	0	-7
				average	2	9	4	-10
100	100	0	0		69	96	6	-24
100	100	0	0		80	83	-1	-14
				average	71	90	3	-19
0	0	100	100		-1	5	64	67
0	0	100	100		3	5	64	65
				average	1	5	64	66

Load Cells 1 & 2 : (100 + 100) kg = ((71-2) + (90-9)) mv

200 kg = 150 mv

$$dy = 1.33 \cdot dx$$

where dy = change in mass on the load cell (kg)

dx = change in reading (mv).

Load Cells 3 & 4 : (100 + 100) kg = ((64-4) + (66+10)) mv

200 kg = 136 mv

$$dy = 1.47 \cdot dx$$

Calibration of the Applicator Nozzles

The weight of water which passed through each nozzle over a given time period, and at a controlled water pressure, was measured and the flow rates were calculated.

nozzle # and rating	time interval (s)		weight of water (g) 415 kPa (60 psi)	552 kPa (80 psi)
80010	30		247.8	292.2
			250.9	292.6
(0.38 L/min			248.2	285.8
(0.10 USGPM)			252.5	288.3
at 415 kPa)			248.2	290.0
		average	249.5	289.8
80015	30		348.8	396.2
			347.4	398.3
(0.57 L/min			348.2	401.0
(0.15 USGPM))			346.5	396.0
			350.4	398.3
		average	348.3	398.0
80020	30		469.5	543.7
			465.2	542.7
(0.76 L/min			475.0	550.6
(0.20 USGPM))			461.2	549.0
			466.1	552.8
		average	467.4	547.8
80030	20		449.7	523.2
			444.4	520.6
(1.14 L/min			454.6	524.0
0.30 USGPM))			460.2	519.0
			454.8	520.2
			438.7	526.3
			451.3	524.8
			446.8	516.3
		average	450.1	521.8

nozzle #	flowrate (L/min and (USGPM)) 415 kPa	552 kPa
80010	0.50 (0.13)	0.58 (0.15)
80015	0.70 (0.18)	0.80 (0.21)
80020	0.93 (0.25)	1.10 (0.29)
80030	1.35 (0.36)	1.57 (0.41)

Calibration of the Pressure Transducer

The signal conditioner provided the excitation voltage and the output signal conditioning for the pressure transducer. The output voltage from the signal conditioner was recorded at atmospheric pressure and at 552 kPa (80 psi) of pressure.

atmospheric pressure (101.3 kPa (14.7 psi)) :

readings = -36.43, -33.53, -34.10, -31.31, -35.70 mv
average = -34.21 mv

552 kPa (80 psi) pressure :

readings = -12.05, -11.26, -16.32, -10.94, -17.80 mv
average = -13.67 mv

$$y = 851.15 + (21.93 \cdot x)$$

where y = pressure (kPa)
x = reading (mv)

APPENDIX B

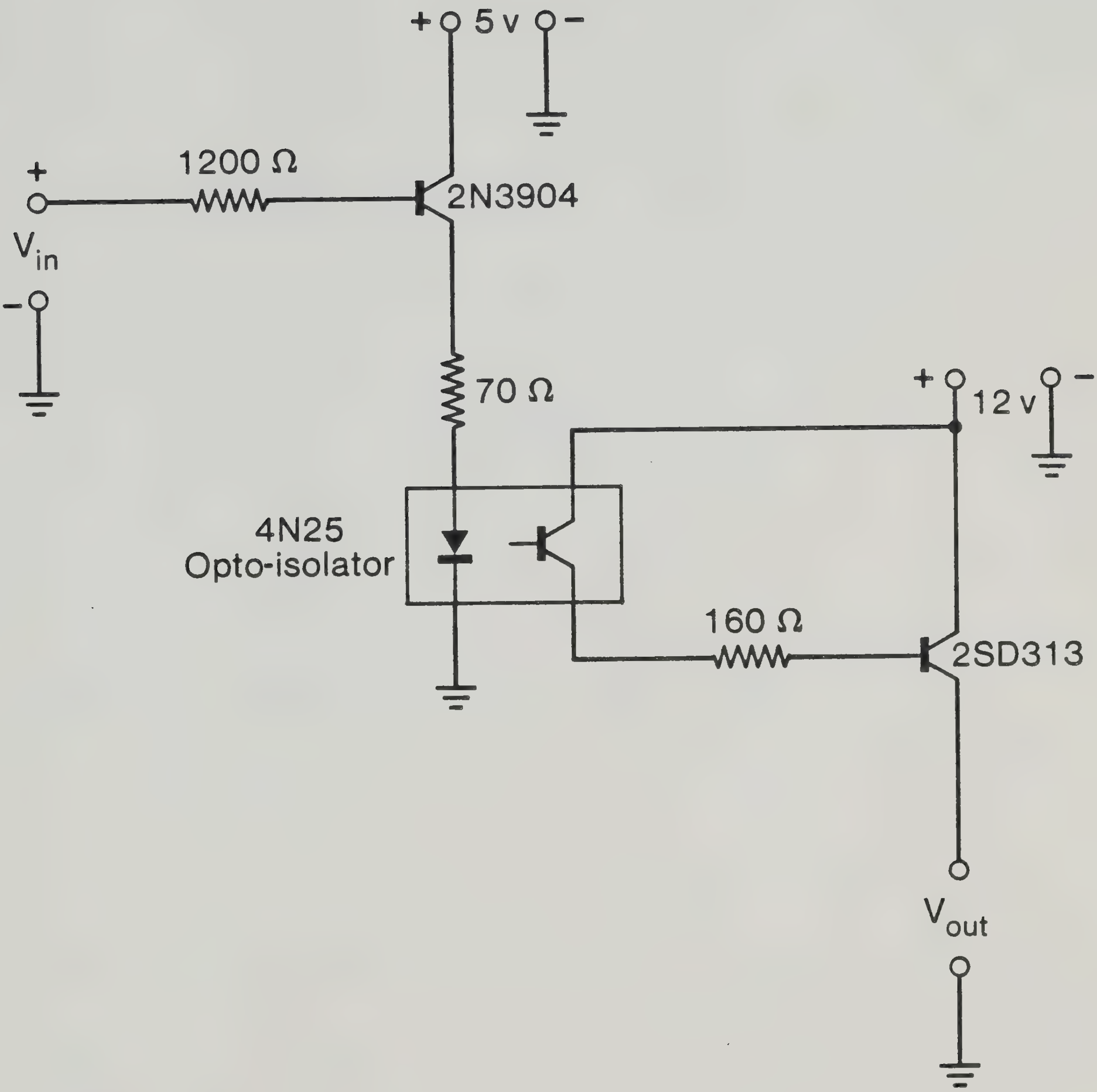
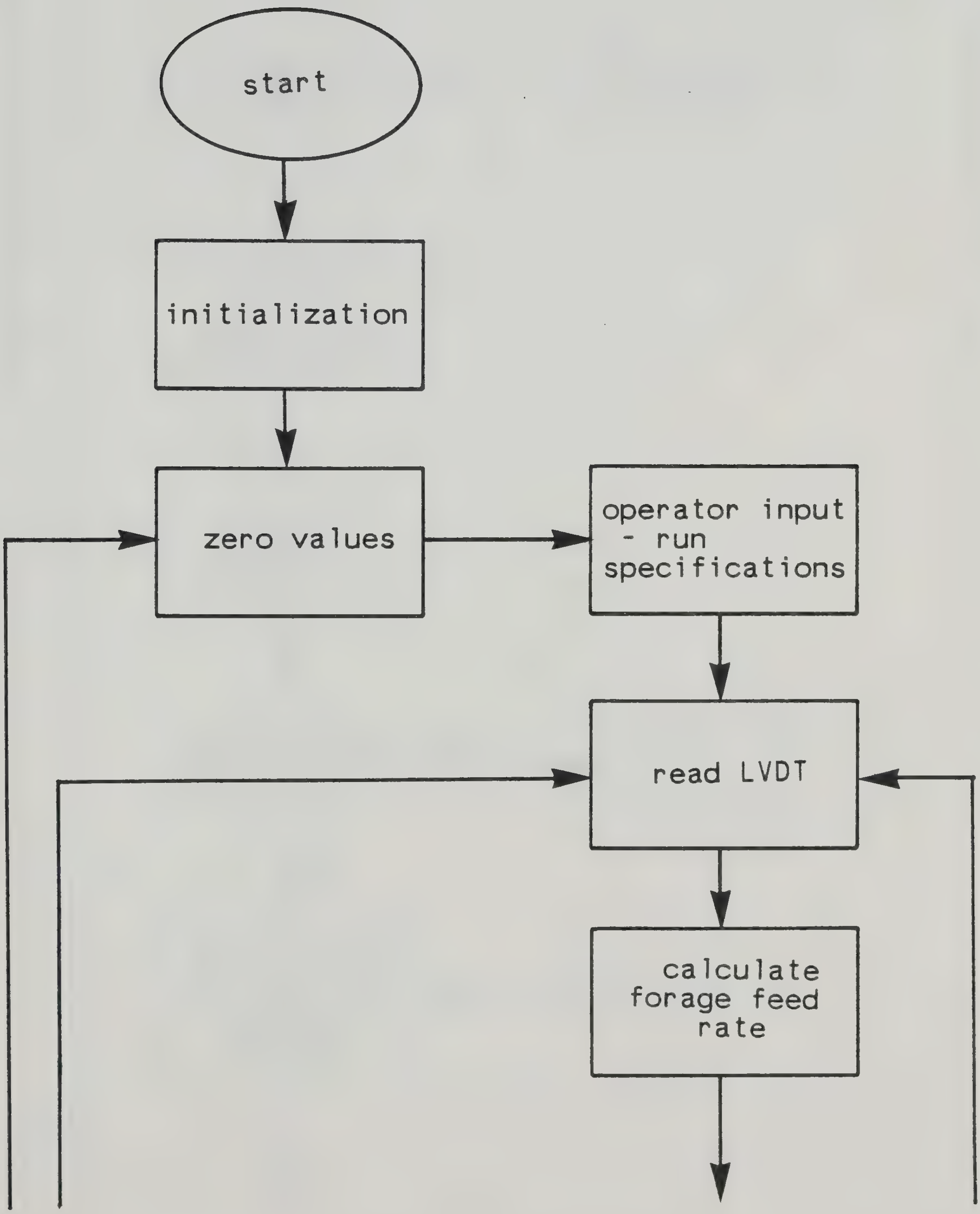
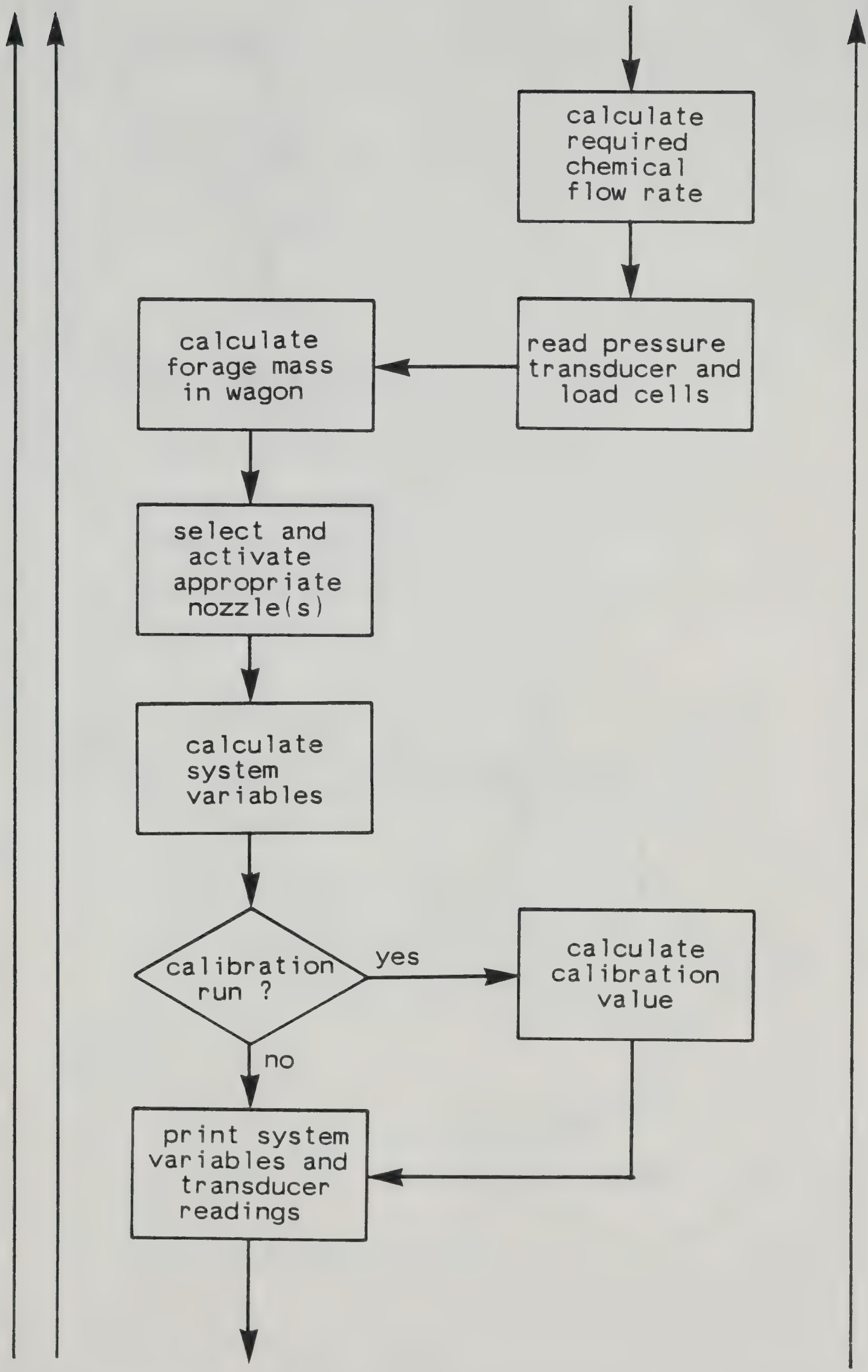


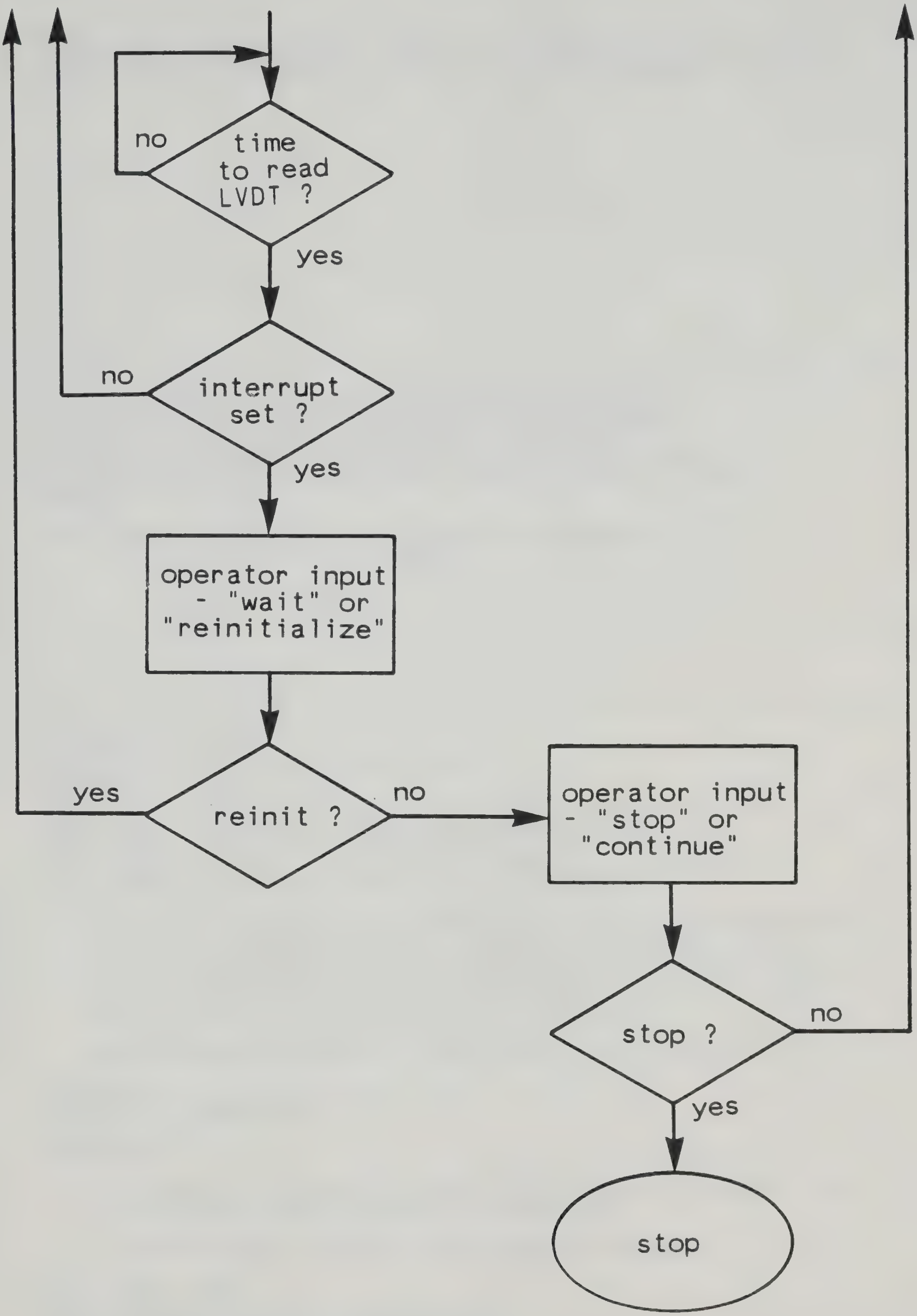
Figure B1 Circuit diagram of the power amplifier located between the MINC minicomputer and each solenoid during the preliminary study.

APPENDIX C

Flowchart of the chemical application control program for the MINC minicomputer during the preliminary study.




calculate required chemical flow rate
read pressure transducer and load cells
calculate forage mass in wagon
select and activate appropriate nozzle(s)
calculate system variables
calibration run ?
yes
calculate calibration value
no
print system variables and transducer readings


time
to read
LVDT ?
no
yes
interrupt
set ?
no
yes
operator input
- "wait" or
"reinitialize"
reinit ?
yes
no
operator input
- "stop" or
"continue"
stop ?
no
yes
stop

Chemical application control program for the MINC minicomputer during the preliminary study.

```
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
C     MINC MINICOMPUTER PROGRAM FOR DATA COLLECTION ON THE
C     DISPLACEMENT OF A FORAGE HARVESTER FEEDROLL, FORAGE
C     FEED RATE, CHEMICAL APPLICATION RATE AND CHEMICAL
C     APPLICATION PRESSURE, AND FOR THE MINICOMPUTER CONTROL
C     OF THE CHEMICAL APPLICATION RATE (CHEMICAL WEIGHT / FORAGE
C     WEIGHT).
C
C     JULY 1982   DEPARTMENT OF AGRICULTURAL ENGINEERING
C                 UNIVERSITY OF ALBERTA
C
C                 SANDRA STURTON
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
C
C          INITIALIZATION
C-----------------------------------------------------------------------
    2 OPEN(UNIT=2,NAME='LP:')
      DIMENSION INFO(40)
      INTEGER*4 ITIME,IHRS,IMIN,ISEC,ITCK
      INTEGER I1,JA5,JAG,JCAL,I3
      REAL LOAD1,LOAD2,LOAD3,LOAD4,LO1,LO2,LO3,LO4,FORATE,T4,FLO
      REAL INFOWA,LAFOWA,CUFOWA,T2,T3,FL1,PR1,T8,LAFLO
      REAL TERRUP,PRESS,OFF1,OFFSET,A5,IN1,T5,T6,T7,T9,CA
      REAL INIWAG,LVDTSU,A1,A2,TO,T1,DCAL,LVDTOT,WAFLOW,CUFLO,CB
      REAL INFOLV,CUFOLV,LVDT,LVDTO,LVDTF,LVDTC,CUAPR2
C
C         IDATA IS THE VALUE OF THE OUTPUT WORD WHICH CONTROLS THE NOZZLES.
C         IOUT IS THE OUTPUT WORD WHICH CONTROLS THE NOZZLES.
C         FLO IS THE CURRENT CHEMICAL FLOW THROUGH THE NOZZLES (FROM
C            CALIBRATIONS AT 550 KPA OF PRESSURE).
C         WAFLO IS THE CALCULATED CHEMICAL FLOW REQUIRED.
C
C         THE NOZZLES ARE INITIALLY TURNED "OFF" - NO CHEMICAL FLOW.
C
      IDATA=0111
      IOUT=DOUT(,,IERR,IDATA)
      FLO=0.0
      WAFLOW=0.0
C
C         GTIM AND CVTTIM ARE MINC SUBROUTINES TO READ THE CURRENT TIME.
C         TIME "ZERO" IS WHEN THE MINC IS POWERED ON.
C
C         T9 IS THE STARTUP TIME OF THIS PROGRAM IN SECONDS.
C
      CALL GTIM(ITIME)
      CALL CVTTIM(ITIME,IHRS,IMIN,ISEC,ITCK)
      T9=(IHRS*3600)+(IMIN*60)+ISEC+(ITCK/60)
```

```
      T8=0.0
C-------------------------------------------------------------------------------
C          PROVIDE A LIST OF THE ORDER OF THE VARIABLES BEING PRINTED.
C-------------------------------------------------------------------------------
      WRITE(2,30)
      WRITE(2,31)
      WRITE(2,32)
      WRITE(2,33)
      WRITE(2,34)
      WRITE(2,35)
   30 FORMAT(' T1        T4        A5        A3')
   31 FORMAT(' PRESS     LVDT')
   32 FORMAT(' LOAD1     LOAD2     LOAD3     LOAD4')
   33 FORMAT(' CUFOWA    CUFOLV    INFOWA    INFOLV')
   34 FORMAT(' CUFLO     CUAPR2')
   35 FORMAT(' FORATE    WAFLOW    FLO       IDATA')
  180 WRITE(2,36)
   36 FORMAT(' *********************************')
C-------------------------------------------------------------------------------
C          ZERO VALUES INITIALLY.
C-------------------------------------------------------------------------------
C           L1 AND L2 ARE IDENTIFIERS OF THE FIRST PROGRAM LOOP IN
C              EACH RUN, AND ARE USED TO SET THE INITIAL LOAD CELL
C              READINGS.
C
      L1=0
      L2=0
      LAFLO=0.0
      LAFOWA=0.0
      CUFOLV=0.0
      CUFLO=0.0
      LVDTOT=0.0
      CA=0.0
      CB=0.0
      A5=0.0
      A1=0.0
C-------------------------------------------------------------------------------
C          KEYBOARD ENTRY OF THE SPECIFICATIONS OF THIS RUN
C-------------------------------------------------------------------------------
C          LVDTO IS THE CURRENT READING FROM THE LVDT AT ZERO DISPLACEMENT.
C          LVDTF IS THE CURRENT READING FROM THE LVDT AT MAXIMUM DISPLACEMENT.
C          LVDTC WAS THE READING FROM THE LVDT AT MAXIMUM DISPLACEMENT FOR
C             THE RUN FROM WHICH THE CALIBRATION CONSTANTS FOR THIS RUN
C             WERE OBTAINED. THE VALUE OF LVDTC IS EQUAL TO THE LVDTF VALUE IF
C             THIS RUN IS CALCULATING CALIBRATION CONSTANTS AS IT PROGRESSES.
C
C          JA5 IS A "FORAGE WAGON HOOKED IN" IDENTIFIER.
C
  190 WRITE(6,10)
```

```
   10 FORMAT(' ENTER LVDT READINGS AT NO, FULL, CALIB DEFLECTION')
      READ(5,11)LVDTO
      READ(5,11)LVDTF
      READ(5,11)LVDTC
   11 FORMAT(F8.2)
      WRITE(2,12)
      WRITE(2,39)LVDTO,LVDTF,LVDTC
   12 FORMAT(' LVDTO     LVDTF     LVDTC')
      WRITE(6,13)
   13 FORMAT(' FORAGE WAGON HOOKED IN? YES--1, NO--0')
      READ(5,14)JA5
   14 FORMAT(I1)
      IF (JA5.EQ.0) GO TO 230
      IF (JA5.NE.1) GO TO 190
  200 WRITE(2,15)
   15 FORMAT(' THE FORAGE WAGON IS HOOKED IN')
C
C          IF THE FORAGE WAGON IS HOOKED IN, THE PROGRAM CAN RUN
C             USING PREVIOUSLY CALCULATED CALIBRATION VALUES OR
C             CALCULATING CALIBRATION VALUES AS IT PROGRESSES.
C
C          JCAL IS A CALIBRATION RUN IDENTIFIER.
C
  220 WRITE(6,16)
   16 FORMAT(' CALIBRATION RUN--1; NOT--0')
      READ(5,14)JCAL
      IF (JCAL.EQ.0) GO TO 240
      IF (JCAL.NE.1) GO TO 220
      WRITE(2,17)
   17 FORMAT(' CALIBRATION RUN')
      GO TO 250
C
C          IF THE FORAGE WAGON IS NOT HOOKED IN, THE PROGRAM MUST
C             USE PREVIOUSLY CALCULATED CALIBRATION VALUES.
C
  230 WRITE(2,18)
   18 FORMAT(' THE FORAGE WAGON IS NOT HOOKED IN')
  240 WRITE(2,19)
      WRITE(6,20)
   19 FORMAT(' NON-CALIBRATION RUN')
   20 FORMAT(' ENTER CALIBRATION CONSTANTS, CA AND CB')
C
C           CA AND CB ARE THE CALIBRATION CONSTANTS OF FORAGE
C              HARVEST WEIGHT PER LVDT MILLIVOLT READING,
C              AND ARE ENTERED ON THE KEYBOARD BY THE OPERATOR.
C
      READ(5,21)CA
      READ(5,21)CB
   21 FORMAT(F8.5)
```

```
      WRITE(2,22)
      WRITE(2,23)CA,CB
   22 FORMAT(' CALIBRATION CONSTANTS,CA AND CB ARE :')
   23 FORMAT(F8.5,1X,F8.5)
  250 CLOSE(UNIT=2)
C-----------------------------------------------------------------------
C        READ 100 LVDT VALUES (VOLTS) AT 0.05 SECOND INTERVALS, AND CONVERT
C        THE AVERAGE TO MILLIVOLTS.
C-----------------------------------------------------------------------
C         LVDTSU IS THE SUM OF THE 100 LVDT READINGS DURING THIS LOOP (VOLTS).
C         LVDT IS AN INDIVIDUAL LVDT READING DURING THIS LOOP (VOLTS), AND IS
C            THE AVERAGE OF THE 100 LVDT READINGS OUTSIDE OF THE LOOP (MV).
C         OFF1 IS THE SUM OF THE 100 GROUND DIFFERENTIAL READINGS DURING
C            THIS LOOP (VOLTS).
C         OFFSET IS AN INDIVIDUAL GROUND DIFFERENTIAL READING DURING THIS LOOP
C            (VOLTS), AND IS THE AVERAGE OF THE 100 GROUND DIFFERENTIAL
C            OUTSIDE OF THE LOOP (VOLTS).
C         T1 IS THE TIME AT WHICH A PROGRAM CYCLE BEGINS (SECONDS).
C
C
  261 CALL GTIM(ITIME)
      CALL CVTTIM(ITIME,IHRS,IMIN,ISEC,ITCK)
      T1=(IHRS*3600)+(IMIN*60)+ISEC+(ITCK/60)
  280 OPEN(UNIT=2,NAME='LP:')
      OFF1=0
      LVDTSU=0.000
      DO 300 I1=1,100
      A2=I1*0.05
  320 CALL GTIM(ITIME)
      CALL CVTTIM(ITIME,IHRS,IMIN,ISEC,ITCK)
      T3=(IHRS*3600)+(IMIN*60)+ISEC+(ITCK/60)
      T2=T3-T1
      IF (T2.LT.A2) GO TO 320
      LVDT=CAD2FP(IADINP(0,6))
      LVDTSU=LVDTSU+LVDT
      OFFSET=CAD2FP(IADINP(0,11))
      OFF1=OFF1+OFFSET
  300 CONTINUE
      OFFSET=OFF1/100
      LVDT=(LVDTC/LVDTF)*(LVDTSU-OFF1)*10-LVDTO
C-----------------------------------------------------------------------
C         CALCULATE FORAGE FEED RATE AND THE REQUIRED CHEMICAL
C         FLOWRATE.
C-----------------------------------------------------------------------
C         FORATE IS THE CALCULATED FORAGE FEED RATE (TONNES/HOUR) OVER
C            THE PREVIOUS FIVE SECONDS, BASED UPON THE CALCULATED (A1) OR
C            KEYBOARD-ENTRY (CA, CB) CALIBRATION VALUES.
C         WAFLOW IS THE REQUIRED CHEMICAL FLOWRATE (LITERS/MIN)
C            BASED UPON THE CURRENT FORAGE FEED RATE, A CHEMICAL
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```
C            APPLICATION RATE OF 3.5 KG SULPHUR DIOXIDE / TONNE FORAGE,
C            AND A SULPHUR DIOXIDE DENSITY OF 1.39 KG / LITER.
C
      IF(JCAL.EQ.0) GO TO 302
      FORATE=LVDT*A1
      GO TO 304
  302 FORATE=CA+(LVDT*CB)
  304 WAFLOW=FORATE*0.04197
C-----------------------------------------------------------------------
C         READ PRESSURE TRANSDUCER,
C         FORAGE WAGON LOAD CELLS 20 TIMES,
C         AND AVERAGE EACH OF THEM.
C-----------------------------------------------------------------------
C         PR1 IS THE SUM OF THE 20 PRESSURE TRANSDUCER READINGS DURING THIS
C            LOOP (VOLTS).
C         PRESS IS AN INDIVIDUAL PRESSURE TRANSDUCER READING DURING THIS
C            LOOP (VOLTS).
C         LO1, LO2, LO3 AND LO4 ARE EACH THE SUM OF ONE OF THE 4 FORAGE
C            WAGON LOAD CELLS DURING THIS LOOP (VOLTS).
C         LOAD1, LOAD2, LOAD3 AND LOAD4 ARE EACH AN INDIVIDUAL FORAGE
C            WAGON LOAD CELL READING DURING THIS LOOP (VOLTS).
C
C         THE SIGNAL FROM LOAD CELL 1 WAS INPUT ON CHANNEL 1.
C         THE SIGNAL FROM THE SUM OF LOAD CELLS 1 AND 2 WAS INPUT ON
C            CHANNEL 2.
C         THE SIGNAL FROM LOAD CELL 3 WAS INPUT ON CHANNEL 3.
C         THE SIGNAL FROM THE SUM OF LOAD CELLS 3 AND 4 WAS INPUT ON
C            CHANNEL 4.
C
      PR1=0.0
      LO1=0.0
      LO2=0.0
      LO3=0.0
      LO4=0.0
      DO 72 K3=1,20
      PRESS=CAD2FP(IADINP(0,7))
      PR1=PR1+PRESS
      LOAD1=CAD2FP(IADINP(0,1))
      LOAD2=CAD2FP(IADINP(0,2))-LOAD1
      LOAD3=CAD2FP(IADINP(0,3))
      LOAD4=CAD2FP(IADINP(0,4))-LOAD3
      LO1=LO1+LOAD1
      LO2=LO2+LOAD2
      LO3=LO3+LOAD3
      LO4=LO4+LOAD4
   72 CONTINUE
C-----------------------------------------------------------------------
C        CONVERT LINE PRESSURE AND FORAGE SWITCH READINGS TO
C        MILLIVOLTS.
```

```
C          CONVERT FORAGE WAGON LOAD CELL READINGS TO KILOGRAMS.
C-----------------------------------------------------------------------
C          INIWAG IS THE SUM OF THE INITIAL FORAGE WAGON LOAD CELLS (KG).
C          LOAD1, LOAD2, LOAD3 AND LOAD4 ARE EACH THE AVERAGE WEIGHT
C             MEASURED BY ONE OF THE FORAGE WAGON LOAD CELLS (KG).
C          PRESS IS THE AVERAGE READING MEASURED BY THE PRESSURE
C             TRANSDUCER (MV).
C
C          THE DIFFERENTIAL GROUND READING HAS BEEN SUBTRACTED FROM
C             ALL OF THE READINGS.
C
      LOAD1=(LO1/20-OFFSET)*1330
      LOAD2=(LO2/20-OFFSET)*1330
      LOAD3=(LO3/20-OFFSET)*1470
      LOAD4=(LO4/20-OFFSET)*1470
      IF(L1.GT.0) GOTO 340
      INIWAG=LOAD1+LOAD2+LOAD3+LOAD4
      L1=1
  340 PRESS=(PR1/20-OFFSET)*1000
      IF (L2.GT.0) GOTO 480
      L2=1
C-----------------------------------------------------------------------
C           SELECT AND ACTIVATE NOZZLE(S)
C-----------------------------------------------------------------------
  480 IDATA=0110
      FLO=0.580
      IF(WAFLOW.GT.0.70) IDATA=1101
      IF(WAFLOW.GT.0.70) FLO=.796
      IF(WAFLOW.GT.0.95) IDATA=0010
      IF(WAFLOW.GT.0.95) FLO=1.096
      IF(WAFLOW.GT.1.35) IDATA=1111
      IF(WAFLOW.GT.1.35) FLO=1.565
      IF(WAFLOW.GT.1.65) IDATA=1100
      IF(WAFLOW.GT.1.65) FLO=1.675
      IF(WAFLOW.GT.1.80) IDATA=1001
      IF(WAFLOW.GT.1.80) FLO=1.891
      IF(WAFLOW.GT.2.15) IDATA=0101
      IF(WAFLOW.GT.2.15) FLO=2.361
      IF(WAFLOW.GT.2.55) IDATA=1011
      IF(WAFLOW.GT.2.55) FLO=2.661
      IF(WAFLOW.GT.2.85) IDATA=0100
      IF(WAFLOW.GT.2.85) FLO=2.941
      IOUT=DOUT(,,IERR,IDATA)
C
C         T5 IS THE TIME AT WHICH THE PREVIOUS NOZZLE WAS TURNED
C            ON (SECONDS).
C         T9 IS THE LENGTH OF TIME FOR WHICH THE NOZZLES WERE ALL
C            "OFF" DUE TO AN "INTERRUPT" (SECONDS).
C         T4 IS THE LENGTH OF TIME THAT THE PREVIOUS NOZZLE WAS
```

```
C          OPERATING (LENGTH OF PROGRAM CYCLE) (SECONDS).
C       T8 IS THE PRESENT TIME - THE TIME AT WHICH THE PRESENT
C          NOZZLE WAS TURNED ON (SECONDS).
C
      T5=T8
      CALL GTIM(ITIME)
      CALL CVTTIM(ITIME,IHRS,IMIN,ISEC,ITCK)
      T8=(IHRS*3600)+(IMIN*60)+ISEC+(ITCK/60)
      T4=T8-T5-T9
      T9=0.0
C-----------------------------------------------------------------------
C          CALCULATE SYSTEM PARAMETERS
C-----------------------------------------------------------------------
C          INFOLV IS THE FORAGE WEIGHT HARVESTED (KG) DURING THE PREVIOUS
C             PROGRAM CYCLE, BASED UPON THE LVDT READING.
C          LVDTTOT IS THE SUM OF THE LVDT READINGS (MV) OVER THE ENTIRE RUN.
C          CUFLO IS THE CUMULATIVE WEIGHT OF CHEMICAL USED (KG),
C             BASED UPON THE CALIBRATED FLOWRATES OF THE NOZZLES.
C          CUFOLV IS THE CUMULATIVE WEIGHT OF FORAGE HARVESTED (KG), BASED
C             UPON THE LVDT READING.
C          CUFOWA IS THE CUMULATIVE CHANGE IN FORAGE WAGON WEIGHT (KG), BASED
C             UPON THE FORAGE WAGON LOAD CELL READINGS.
C          INFOWA IS THE CHANGE IN FORAGE WAGON WEIGHT (KG) DURING THE PREVIOUS
C             PROGRAM CYCLE, BASED UPON THE FORAGE WAGON LOAD CELL READINGS.
C          CUAPR2 IS THE APPLICATION RATE (KG / KG) SINCE THE START OF THE RUN,
C             BASED UPON THE FORAGE WAGON LOAD CELL READINGS AND THE
C             CALIBRATED FLOWRATES OF THE NOZZLES.
C          LAFOWA IS THE CUFOWA DURING THE PREVIOUS PROGRAM CYCLE (KG).
C          LAFLO IS THE FLO DURING THE PREVIOUS PROGRAM CYCLE (L/MIN).
C
      INFOLV=FORATE*T4/3.6
      LVDTOT=LVDTOT+LVDT
      CUFLO=CUFLO+(LAFLO*T4*0.02317)
      CUFOLV=CUFOLV+INFOLV
      CUFOWA=LOAD1+LOAD2+LOAD3+LOAD4-INIWAG
      INFOWA=CUFOWA-LAFOWA
      IF (JCAL.NE.0) GO TO 6000
  420 CUAPR2=100*CUFLO/(CUFOWA-(CUFLO/2))
C
C          UPDATE THE "PREVIOUS CYCLE" VALUES.
C
  460 LAFOWA=CUFOWA
      LAFLO=FLO
C-----------------------------------------------------------------------
C          PRINT TRANSDUCER INPUTS AND SYSTEM PARAMETERS
C-----------------------------------------------------------------------
      WRITE(2,38)T1,T4,A5,A3
      WRITE(2,41)PRESS,LVDT
      WRITE(2,37)LOAD1,LOAD2,LOAD3,LOAD4
```

```
      WRITE(2,37)CUFOWA,CUFOLV,INFOWA,INFOLV
      WRITE(2,41)CUFLO,CUAPR2
      WRITE(2,40)FORATE,WAFLOW,FLO,IDATA
   37 FORMAT(4(F8.2,1X))
   38 FORMAT(2(F8.2,1X),2(F8.5,1X))
   39 FORMAT(3(F8.2,1X))
   40 FORMAT(3(F8.2,1X),I8)
   41 FORMAT(2(F8.2,1X))
      CLOSE(UNIT=2)
C-----------------------------------------------------------------------
C         LOOP UNTIL TIME TO START ANOTHER INTEGRATION
C-----------------------------------------------------------------------
C         T7 IS THE TIME IN SECONDS SINCE THE LVDT READINGS WERE
C            BEGUN FOR THIS CYCLE.
C
C         NOTE THAT T7 IS NEVER LESS THAN 5.0, AND THE PROGRAM
C            PROCEEDS IMMEDIATELY WITHOUT LOOPING BACK TO 700.
C            THIS LOOP WAS INCLUDED TO ALLOW MODIFICATION OF THE
C            CYCLE TIME OF THIS PROGRAM.
C
  700 CALL GTIM(ITIME)
      CALL CVTTIM(ITIME,IHRS,IMIN,ISEC,ITCK)
      T6=(IHRS*3600)+(IMIN*60)+ISEC+(ITCK/60)
      T7=T6-T1
      IF(T7.LT.5.0) GOTO 700
C-----------------------------------------------------------------------
C         CHECK FOR AN INTERRUPT
C-----------------------------------------------------------------------
  750 TERRUP=1.0*CAD2FP(IADINP(0,10))
      TERRUP=TERRUP-OFFSET
      IF(TERRUP.GT.0.5) GOTO 7000
      GO TO 261
C-----------------------------------------------------------------------
C         CALIBRATION SUBROUTINE
C-----------------------------------------------------------------------
C         A5 IS THE CALCULATED CALIBRATION VALUE (FORAGE HARVEST RATE / LVDT
C            READING = TONNE / (HOUR * MV)) BASED UPON THE CHANGE IN FORAGE
C            WAGON WEIGHT AND THE LVDT READING DURING THE PREVIOUS PROGRAM
C            CYCLE.
C         A1 IS THE CALCULATED CALIBRATION VALUE (TONNE / (HOUR * MV)) BASED
C            UPON THE CUMULATIVE CHANGE IN FORAGE WAGON WEIGHT AND THE SUM
C            OF THE LVDT READINGS.
C
 6000 A5=(INFOWA*3.6)/(LVDT*T4)
      A1=(CUFOWA*3.6)/(LVDTOT*T4)
      GOTO 420
C-----------------------------------------------------------------------
C         INTERRUPT SUBROUTINE
C-----------------------------------------------------------------------
```

```
C          ON AN INTERRUPT, ALL OF THE NOZZLES ARE SHUT "OFF".
C          THE OPERATOR HAS A CHOICE OF RE-INITIALIZING THE RUN, OR
C             OF TEMPORARILY HALTING THE RUN.
C
C          IOLD IS THE NOZZLE CONTROL WORD PREVIOUS TO THE INTERRUPT.
C
 7000 OPEN(UNIT=2,NAME='LP:')
 7010 IOLD=IDATA
      IDATA=0111
      IOUT=DOUT(,,IERR,IDATA)
      WRITE(6,44)
   44 FORMAT(' INTERRUPT.. RE-INIT--1, WAIT--0')
      READ(5,14)JAG
      IF(JAG.EQ.1) GOTO 180
      IF(JAG.NE.0) GOTO 7010
 7600 WRITE(2,57)
   57 FORMAT(' STOP, WAIT, CONTINUE')
C
C           IF THE OPERATOR HAS TEMPORARILY HALTED THE RUN,
C              HE MAY CONTINUE WHEN READY OR STOP THE RUN ENTIRELY.
C
C           IF HE CONTINUES, THE TIME DURING WHICH THE RUN WAS
C              HALTED IS CALCULATED, THEN THE NOZZLES ARE RETURNED
C              TO THE STATE IN WHICH THEY WERE OPERATING BEFORE
C              THE INTERRUPT.
C
      WRITE(6,58)
   58 FORMAT(' ENTER NUMBER TO CONTINUE (0 TO STOP)')
      READ(5,14)I3
      IF(I3.EQ.0) GOTO 9000
      CALL GTIM(ITIME)
      CALL CVTTIM(ITIME,IHRS,IMIN,ISEC,ITCK)
      T9=(IHRS*3600)+(IMIN*60)+ISEC+(ITCK/60)
      T9=T9-T6
      IDATA=IOLD
      IOUT=DOUT(,,IERR,IDATA)
      GO TO 250
C
C           IF THE OPERATOR STOPS THE RUN, THEN ALL OF THE NOZZLES
C              ARE TURNED "OFF".
C
 9000 IDATA=0111
      IOUT=DOUT(,,IERR,IDATA)
      WRITE(2,59)
   59 FORMAT(' STOPPING PROGRAM EXECUTION')
      CLOSE(UNIT=2)
      GO TO 2
      STOP
      END
```

APPENDIX D

Table D1 System run #1; Farm #1 (Ron Bienert) with 40% dry matter content barley at 19 mm length of cut.

time (s)	forage mass (kg)	feedroll disp. (cm)	chemical flow (L/min)
0	0.0	0.0	0.58
14	-25.3	0.0	0.58
28	43.8	1.7	0.58
42	109.9	0.1	0.58
56	116.1	0.0	0.58
70	101.5	0.0	0.58
84	107.0	2.5	1.57
98	130.9	0.6	0.58
112	206.6	0.9	0.58
126	309.3	0.3	0.58
140	345.7	0.0	0.58
154	402.5	1.1	0.58
168	465.5	0.3	0.58
182	491.2	1.4	0.80
196	633.3	1.0	0.58
210	665.2	1.4	0.80
224	750.7	1.2	0.80
238	819.9	1.4	0.80
252	961.6	0.7	0.58
266	1014.1	0.4	0.58
280	1145.1	1.3	0.80
294	1236.2	2.0	1.57
308	1278.9	1.3	1.10
322	1332.1	0.3	0.58
336	1373.1	0.0	0.58
350	1380.7	0.8	0.58
364	1495.1	1.1	0.80
378	1554.7	0.7	0.58
392	1645.8	0.2	0.58
406	1725.3	1.1	0.80
420	1808.5	0.7	0.58
434	1769.4	0.2	0.58

Table D2 System run #2; Farm #1 (Ron Bienert) with 40% dry matter content barley at 6 mm length of cut.

time (s)	forage mass (kg)	feedroll disp. (cm)	chemical flow (L/min)
0	0.0	2.8	0.58
13	45.0	1.5	0.58
26	173.6	2.2	0.58
40	245.0	1.3	0.58
54	327.6	1.3	0.58
68	370.7	1.4	0.58
82	433.2	1.7	0.58
96	504.5	2.2	0.80
110	571.7	2.1	0.80
124	658.8	1.2	0.58
138	800.9	1.3	0.58
152	857.9	1.2	0.58
166	920.0	0.9	0.58
180	1004.2	0.6	0.58
194	1040.2	0.1	0.58
208	1088.8	0.1	0.58
222	1158.2	1.2	0.58
236	1248.3	2.5	1.10
250	1341.6	1.3	0.58
264	1392.6	1.0	0.58
278	1437.2	0.9	0.58
292	1581.8	1.3	0.80
306	1641.2	0.9	0.58
320	1700.6	1.1	0.58
334	1741.5	2.6	1.57
348	1848.6	2.2	1.10
362	1880.6	1.4	0.80
376	2014.1	2.7	1.57
390	2146.7	2.4	1.10
404	2213.2	3.3	1.67
418	2254.4	2.4	1.10
432	2337.1	2.2	1.10
446	2441.6	0.7	0.58
460	2500.7	2.5	1.10
474	2652.1	2.4	1.10
488	2760.3	1.8	0.80

Table D3 System run #3; Farm #1 (Ron Bienert) with 40% dry matter content barley at 6 mm length of cut.

time (s)	forage mass (kg)	feedroll disp. (cm)	chemical flow (L/min)
0	0.0	2.3	0.58
13	102.9	1.8	0.58
27	247.8	2.2	0.58
40	310.9	1.8	0.80
54	368.0	3.0	1.10
68	477.6	2.1	0.80
82	527.1	0.4	0.58
96	566.1	0.0	0.58

Table D4 System run #4; Farm #1 (Ron Bienert) with 40% dry matter content barley at 6 mm length of cut.

time (s)	forage mass (kg)	feedroll disp. (cm)	chemical flow (L/min)
0	0.0	1.3	0.58
14	-27.8	2.7	1.57
28	72.3	2.6	1.10
42	168.3	1.6	0.80
56	265.8	2.3	1.10
70	290.9	3.5	1.67
84	363.8	1.8	0.80
98	508.2	2.2	1.10
112	524.8	2.6	1.10
126	644.2	2.6	1.10
140	679.3	2.7	1.57
154	775.8	2.1	1.10
168	937.6	1.0	0.58
182	991.0	2.4	1.10
196	1048.0	2.0	1.10
210	1131.7	2.1	1.10
224	1273.4	2.9	1.57
238	1340.8	2.6	1.10
252	1418.4	2.3	1.10
266	1460.2	1.6	0.80
280	1566.2	1.9	1.10
294	1562.6	0.2	0.58
308	1683.0	2.3	1.10
322	1780.0	2.5	1.10
336	1813.5	1.2	0.58
350	1950.3	3.0	1.57
364	1958.8	2.2	1.10
378	2028.4	2.3	1.10
392	2127.1	2.3	1.10
406	2238.0	2.1	1.10
420	2334.6	2.1	1.10
434	2449.7	2.2	1.10
448	2472.5	1.5	0.80
462	2538.8	2.4	1.10
476	2652.7	0.7	0.58
490	2752.6	0.4	0.58

Table D5 System run #5; Farm #1 (Ron Bienert) with 48% dry matter content barley at 6 mm length of cut.

time (s)	forage mass (kg)	feedroll disp. (cm)	chemical flow (L/min)
0	0.0	0.0	0.58
14	35.0	1.1	0.58
23	48.1	1.2	0.58
42	150.3	1.4	0.58
56	189.8	0.0	0.58
70	197.1	0.8	0.58
84	289.5	1.6	0.80
98	390.6	2.8	1.57
112	437.8	1.4	0.58
126	492.6	1.1	0.58
140	614.5	0.6	0.58
154	596.8	0.1	0.58
168	598.2	0.0	0.58
182	594.6	0.0	0.58
196	668.9	0.5	0.58
210	681.0	0.1	0.58
224	733.2	1.0	0.58
238	728.8	0.0	0.58
252	778.2	2.9	1.67
266	832.4	2.4	1.10
280	959.7	2.5	1.10
294	1007.9	0.9	0.58
308	1075.4	1.8	0.80
322	1165.5	1.6	0.80
336	1231.6	2.2	1.10
350	1303.7	1.9	0.80
364	1381.9	2.0	0.80
378	1409.7	1.9	0.80
392	1480.8	2.0	0.80
406	1599.5	2.6	1.10
420	1659.9	2.4	1.10
434	1711.2	1.9	0.80
448	1801.4	2.0	0.80
462	1867.8	1.8	0.80
476	1903.4	1.0	0.58
490	2017.7	1.7	0.80
504	2014.5	1.4	0.58
518	2080.2	1.4	0.58
532	2197.1	1.8	0.80
546	2244.9	0.7	0.58
560	2240.5	0.0	0.58

Table D6 System run #6; Farm #1 (Ron Bienert) with 48% dry matter content barley at 6 mm length of cut.

time (s)	forage mass (kg)	feedroll disp. (cm)	chemical flow (L/min)
0	0.0	0.0	0.58
13	-16.1	0.0	0.58
27	31.4	0.0	0.58
41	37.8	1.3	0.58
55	93.3	1.8	0.80
69	147.1	1.5	0.58
82	203.0	1.2	0.58
96	296.1	2.6	1.10
110	235.7	2.3	1.10
124	325.4	0.0	0.58
138	283.0	0.0	0.58
151	284.7	1.0	0.58
165	323.3	2.0	0.80
179	376.7	1.4	0.58
193	434.9	1.0	0.58
207	460.4	1.6	0.80
221	532.4	1.3	0.58
235	563.5	1.6	0.80
249	687.4	0.8	0.58
263	709.9	1.9	0.80
277	760.7	1.7	0.80
291	869.0	2.3	1.10
305	932.6	1.4	0.58
319	1007.3	3.9	1.67
333	1026.8	1.2	0.58
347	1157.2	1.7	0.80
361	1122.5	2.4	1.10
375	1168.1	1.4	0.58
389	1264.3	1.1	0.58
403	1281.8	1.2	0.58
417	1408.0	1.2	0.58
431	1442.0	0.5	0.58
445	1474.1	1.1	0.58
459	1513.7	0.8	0.58
473	1574.0	2.2	1.10
487	1657.8	2.4	1.10
501	1757.0	1.8	0.80
515	1810.3	2.9	1.10
529	1930.9	1.4	0.58
543	1935.6	1.4	0.58
557	2012.6	1.4	0.58
571	2072.2	1.6	0.80
585	2120.6	1.9	0.80

Table D7 System run #7; Farm #2 (Ron Stelter) with 40% dry matter content barley/oats at 6 mm length of cut.

time (s)	forage mass (kg)	feedroll disp. (cm)	chemical flow (L/min)
0	0.0	1.6	0.58
14	64.4	0.9	0.58
28	103.8	1.4	0.58
42	163.8	1.6	0.58
56	250.2	2.3	0.80
70	312.0	2.0	0.58
84	369.4	0.7	0.58
98	442.8	0.6	0.58
112	534.8	2.0	0.80
126	564.3	2.7	1.10
140	668.1	1.5	0.58
154	781.1	1.8	0.80
168	830.5	3.0	1.10
182	923.7	1.6	0.58
196	968.0	2.1	0.80
210	1054.2	1.2	0.58
224	1128.5	1.3	0.58
238	1206.8	1.9	0.80
252	1355.1	2.0	0.80
266	1362.4	1.0	0.58
280	1461.5	2.2	1.10
294	1568.1	1.4	0.58
308	1612.0	0.4	0.58
322	1655.3	0.3	0.58
336	1710.4	1.5	0.80
350	1669.1	1.8	0.80
364	1778.3	1.4	0.58
378	1862.8	1.0	0.58
392	1894.2	1.2	0.58
406	2017.9	0.9	0.58
420	2009.0	0.3	0.58
434	2088.4	0.5	0.58
448	2131.8	0.5	0.58
462	2126.3	0.5	0.58
476	2208.9	0.6	0.58
490	2274.1	0.4	0.58
504	2337.8	1.0	0.58
518	2391.6	0.4	0.58

Table D8 System run #8; Farm #2 (Ron Stelter) with 40% dry matter content barley/oats at 6 mm length of cut.

time (s)	forage mass (kg)	feedroll disp. (cm)	chemical flow (L/min)
0	0.0	1.1	0.58
14	90.8	1.3	0.58
28	118.1	2.0	1.10
42	176.4	1.9	1.10
56	245.4	0.9	0.58
70	233.5	1.4	0.80
84	330.1	1.5	0.80
98	422.1	1.5	0.80
112	476.9	2.0	1.10
126	593.2	1.2	0.58
140	622.9	0.7	0.58
154	646.5	1.0	0.58
168	772.7	0.9	0.58
182	787.2	1.4	0.80
196	940.2	1.5	0.80
210	922.4	1.7	0.80
224	1038.4	1.6	0.80
238	1042.2	1.6	0.80
252	1164.8	2.5	1.10
266	1171.4	1.3	0.58
280	1293.3	0.8	0.58
294	1321.9	0.8	0.58
308	1476.8	1.1	0.58
322	1468.8	1.3	0.58
336	1577.0	0.7	0.58
349	1688.3	1.1	0.58
363	1654.6	1.2	0.58
377	1729.8	1.4	0.80
391	1780.5	1.5	0.80
405	1840.0	1.0	0.58
419	1854.0	0.5	0.58
433	1917.1	1.0	0.58
447	1961.3	0.7	0.58
461	1988.8	0.3	0.58
475	2040.2	0.2	0.58
489	2067.7	0.3	0.58
503	2083.1	0.0	0.58
517	2157.7	0.2	0.58
531	2145/1	0.5	0.58
545	2252.9	1.4	0.80
559	2292.5	0.0	0.58

Table D9 System run #9; Farm #2 (Ron Stelter) with 40% dry matter content barley/oats at 6 mm length of cut.

time (s)	forage mass (kg)	feedroll disp. (cm)	chemical flow (L/min)
0	0.0	2.3	1.10
13	57.7	3.4	1.67
27	71.1	1.1	0.58
41	183.8	1.0	0.58
55	183.8	1.5	0.80
69	308.2	1.4	0.80
83	418.4	1.3	0.58
97	471.1	1.8	0.80
110	633.6	1.6	0.80
124	637.0	7.8	2.94
138	639.5	3.3	1.67
152	747.5	0.8	0.58
166	869.3	1.2	0.58
180	890.8	1.0	0.58
194	1044.9	1.6	0.80
208	1058.8	1.1	0.58
222	1105.3	2.5	1.10
236	1096.5	2.7	1.57
250	1330.1	3.0	1.57
264	1405.5	2.0	1.10
277	1390.3	1.8	0.80
291	1521.0	2.9	1.57
305	1642.9	1.5	0.80
319	1671.1	1.6	0.80
333	1699.0	1.3	0.58
347	1739.0	1.6	0.80
361	1821.2	0.9	0.58
375	1918.2	1.1	0.58
389	1944.1	3.6	1.89
403	2026.4	3.2	1.57
417	2178.0	2.2	1.10
431	2037.6	0.8	0.58
445	2213.6	0.3	0.58
459	2376.6	2.5	1.10
473	2409.5	1.6	0.80
487	2460.0	1.0	0.58
501	2538.7	1.2	0.58
515	2519.0	1.8	0.80
529	2585.5	1.7	0.80
543	2704.8	0.2	0.58
557	2656.2	0.2	0.58

Table D10 System run #10; Farm #3 (Ed Nickel) with 34% dry matter content barley at 6 mm length of cut.

time (s)	forage mass (kg)	feedroll disp. (cm)	chemical flow (L/min)
0	0.0	2.4	0.58
14	44.8	0.7	0.58
28	94.6	1.6	0.58
42	147.2	2.8	0.58
56	243.1	1.6	0.58
70	348.7	2.4	0.58
84	406.7	3.2	1.10
98	531.4	2.4	0.80
112	621.4	2.3	0.80
126	699.6	2.0	0.80
140	772.9	1.2	0.58
154	861.0	1.2	0.58
168	950.5	1.6	0.58
182	1033.1	0.7	0.58
196	1066.0	1.6	0.58
210	1128.6	1.3	0.58
224	1258.1	1.7	0.80
238	1349.4	2.1	0.80
252	1432.4	2.2	1.10
266	1530.7	1.9	0.80
280	1656.0	1.7	0.80
294	1756.7	2.1	1.10
308	1806.8	1.9	0.80
322	1886.5	1.4	0.58
336	1971.6	1.5	0.80
350	2007.5	1.7	0.80
364	2110.1	1.0	0.58
378	2201.1	2.6	1.10
392	2222.6	1.1	0.58
406	2332.1	2.0	0.80
420	2388.9	1.9	0.80
434	2530.3	1.5	0.58
448	2566.0	2.0	1.10
462	2606.0	2.3	1.10
476	2743.8	2.0	0.80
490	2814.1	1.3	0.58
504	2874.1	1.8	0.80

APPENDIX E

Table E1 Barley calibration runs done at Ellerslie (preliminary study).

Run #	time (s)	crop d.m. (%)	length of cut (mm)	feed rate (t/h)	feedroll disp. (cm)
1	206	52	6	23.8	3.2
2	302	52	6	19.2	1.9
3	104.5	52	6	14.2	1.1
4	202.5	52	6	19.9	3.6
5	81	39	6	17.1	1.2
6	171	39	6	18.7	2.0
7	298	46	6	15.9	1.3
8	58	41	6	15.0	1.0
9	102.5	41	4	20.4	3.4
10	112.5	41	16	20.8	1.1
11	94	41	19	11.7	0.3
12	121.5	41	11	16.6	1.5
13	107	41	8	20.1	1.1
14	125	41	6	7.2	0.3
15	173.5	41	6	14.6	1.6

Table E2 Alfalfa calibration runs done at Ellerslie (preliminary study).

Run #	time (s)	crop d.m. (%)	length of cut (mm)	feed rate (t/h)	feedroll disp. (cm)
1	60	23	6	10.1	0.3
2	65.5	23	4	15.0	1.4
3	92	23	19	9.8	0.3
4	65	23	16	16.0	0.3
5	68.5	23	11	9.6	0.2
6	90.5	23	8	10.1	0.1
7	86.5	26	6	5.3	0.1
8	110	32	6	13.5	0.6
9	100	34	6	19.8	1.3

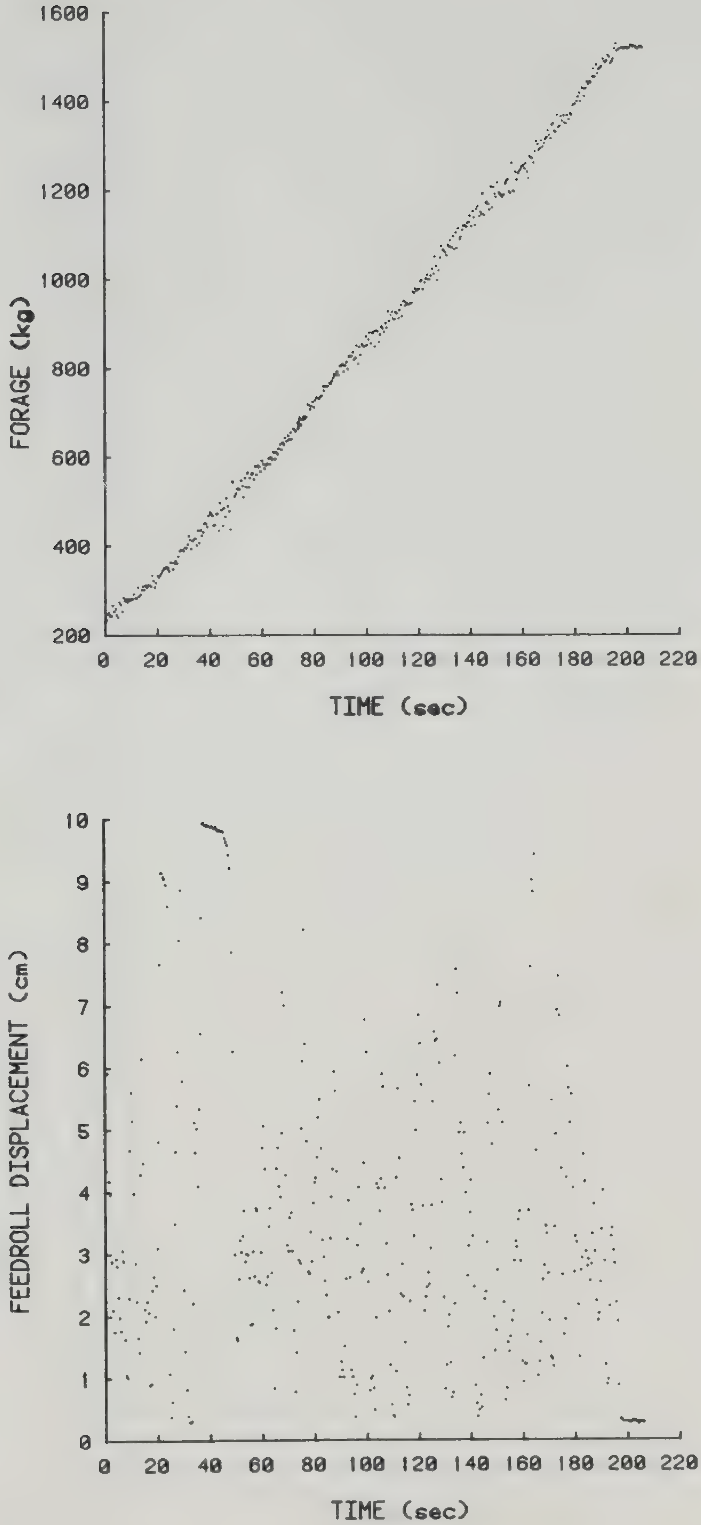


Figure E1 Calibration run #1 with barley : mass of forage in the forage wagon and feedroll displacement versus time.

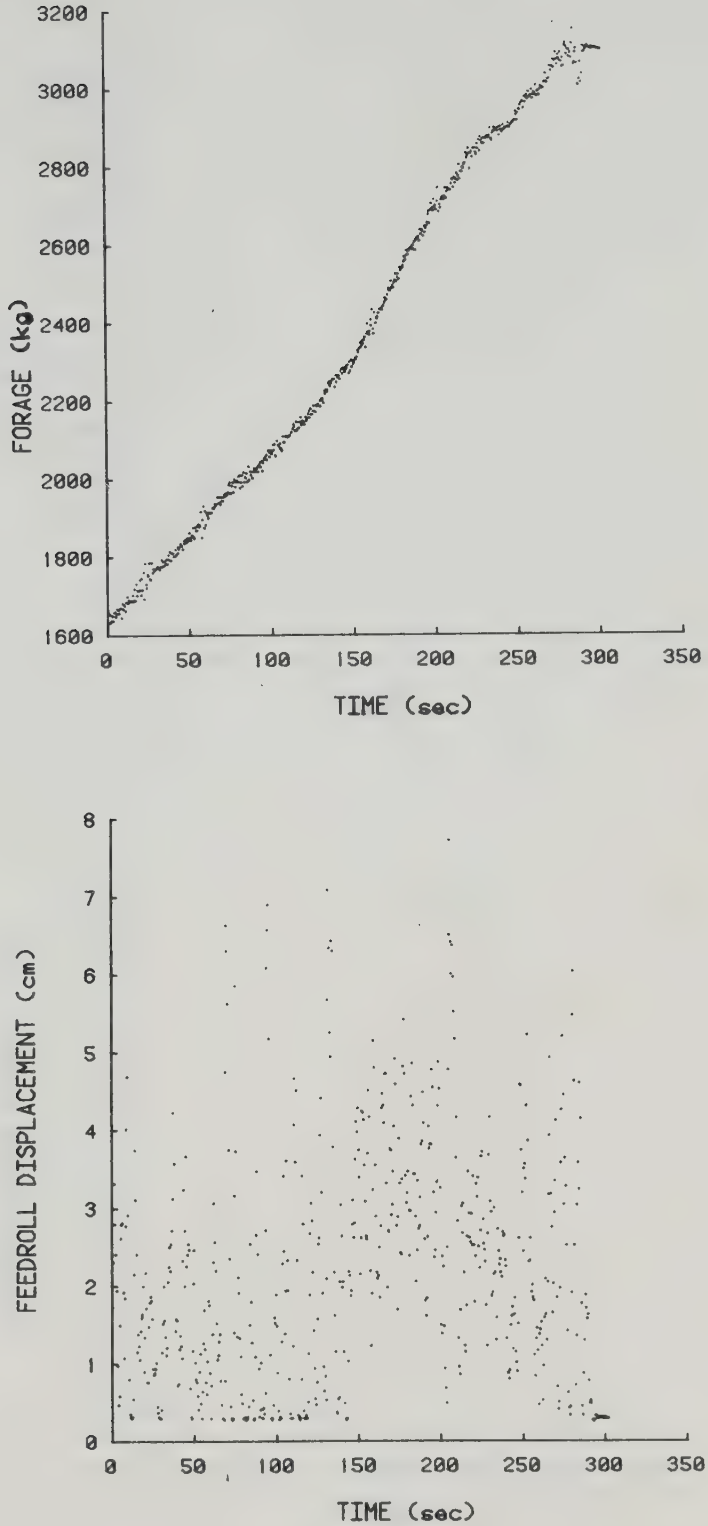


Figure E2 Calibration run #2 with barley : mass of forage in the forage wagon and feedroll displacement versus time.

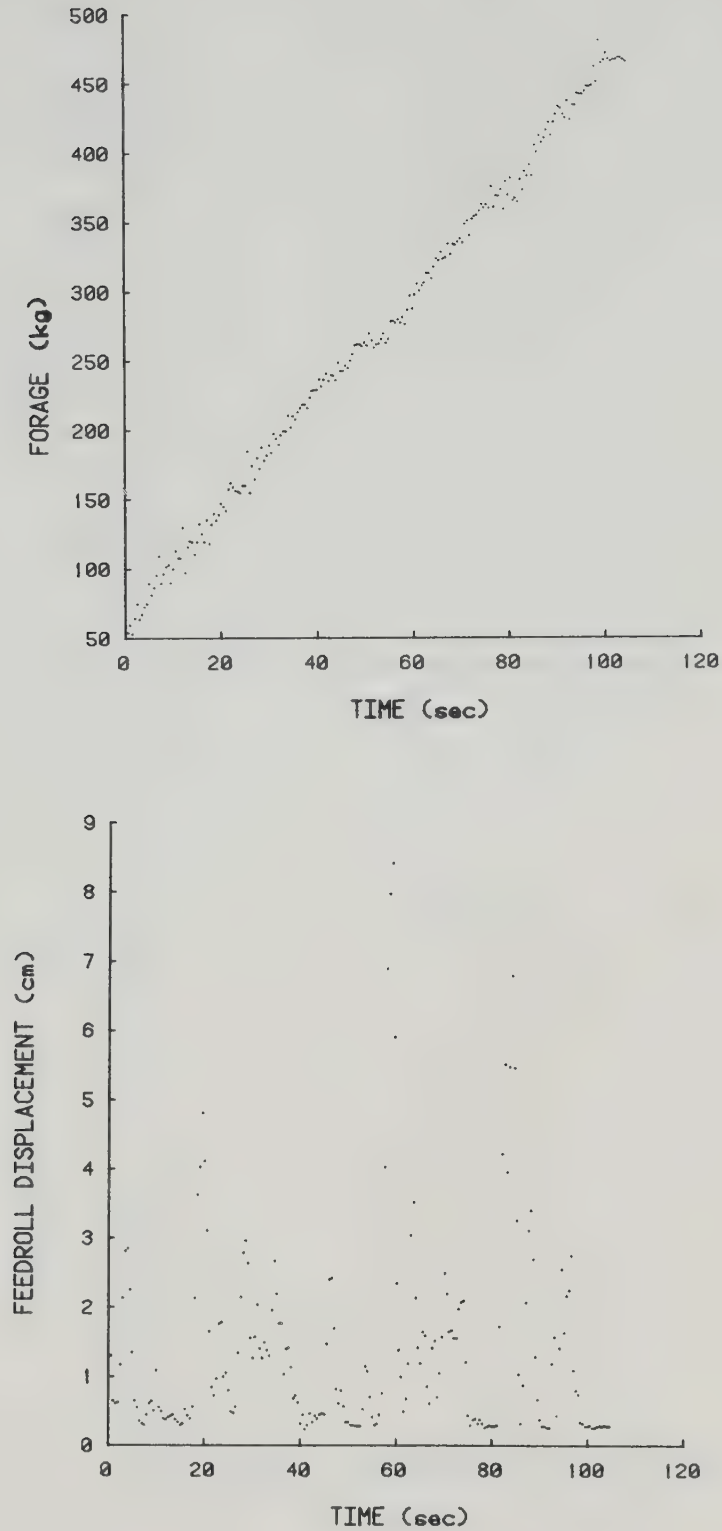


Figure E3 Calibration run #3 with barley : mass of forage in the forage wagon and feedroll displacement versus time.

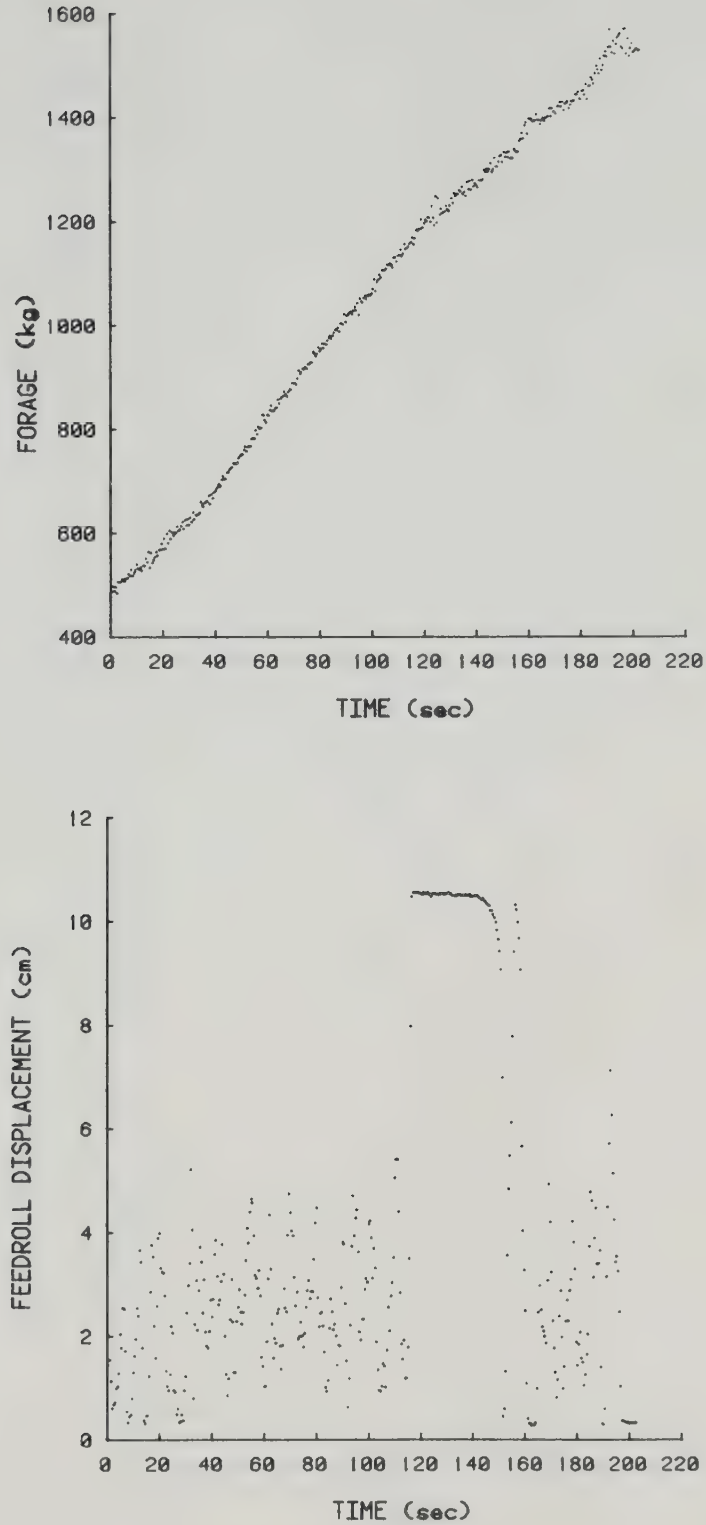
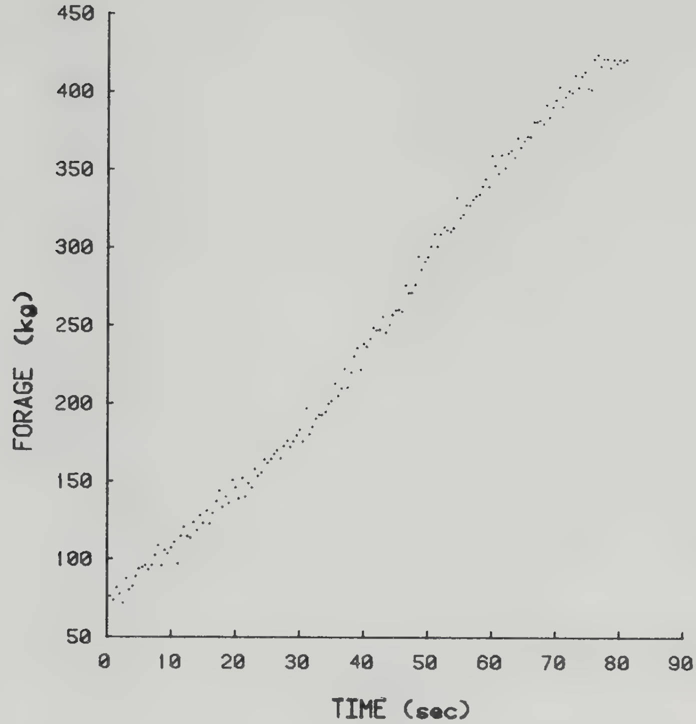


Figure E4 Calibration run #4 with barley : mass of forage in the forage wagon and feedroll displacement versus time.



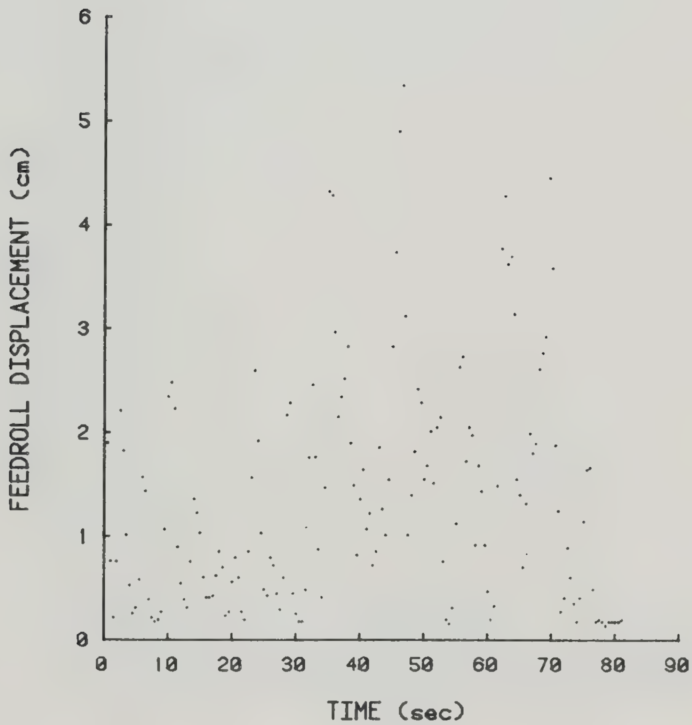
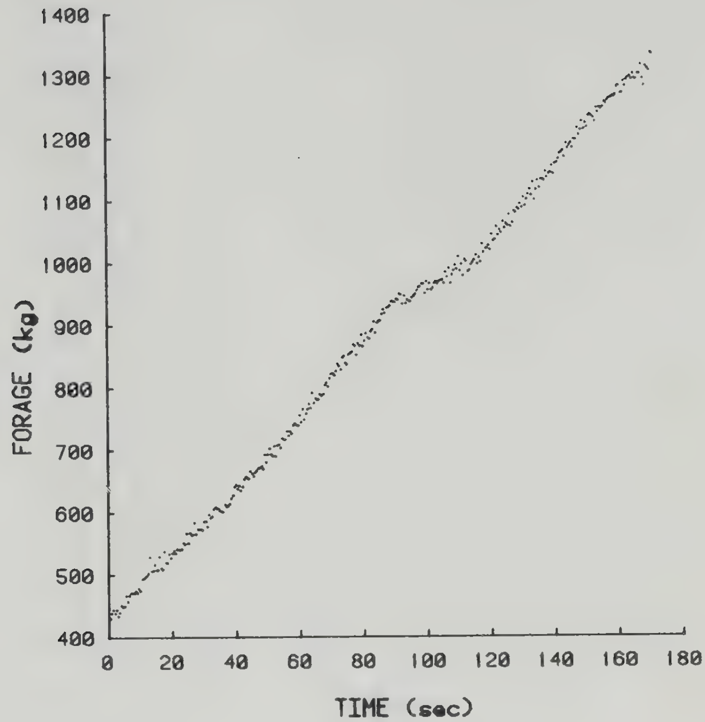


Figure E5 Calibration run #5 with barley : mass of forage in the forage wagon and feedroll displacement versus time.



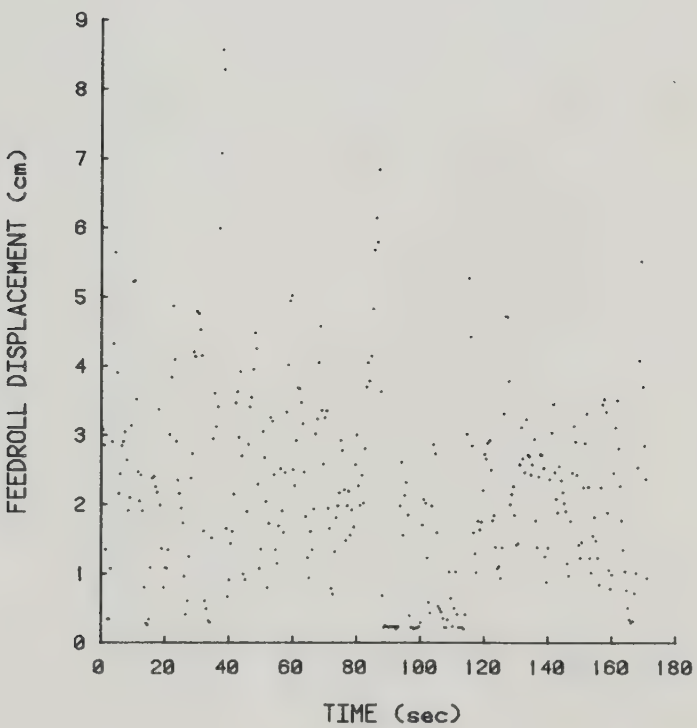


Figure E6 Calibration run #6 with barley : mass of forage in the forage wagon and feedroll displacement versus time.

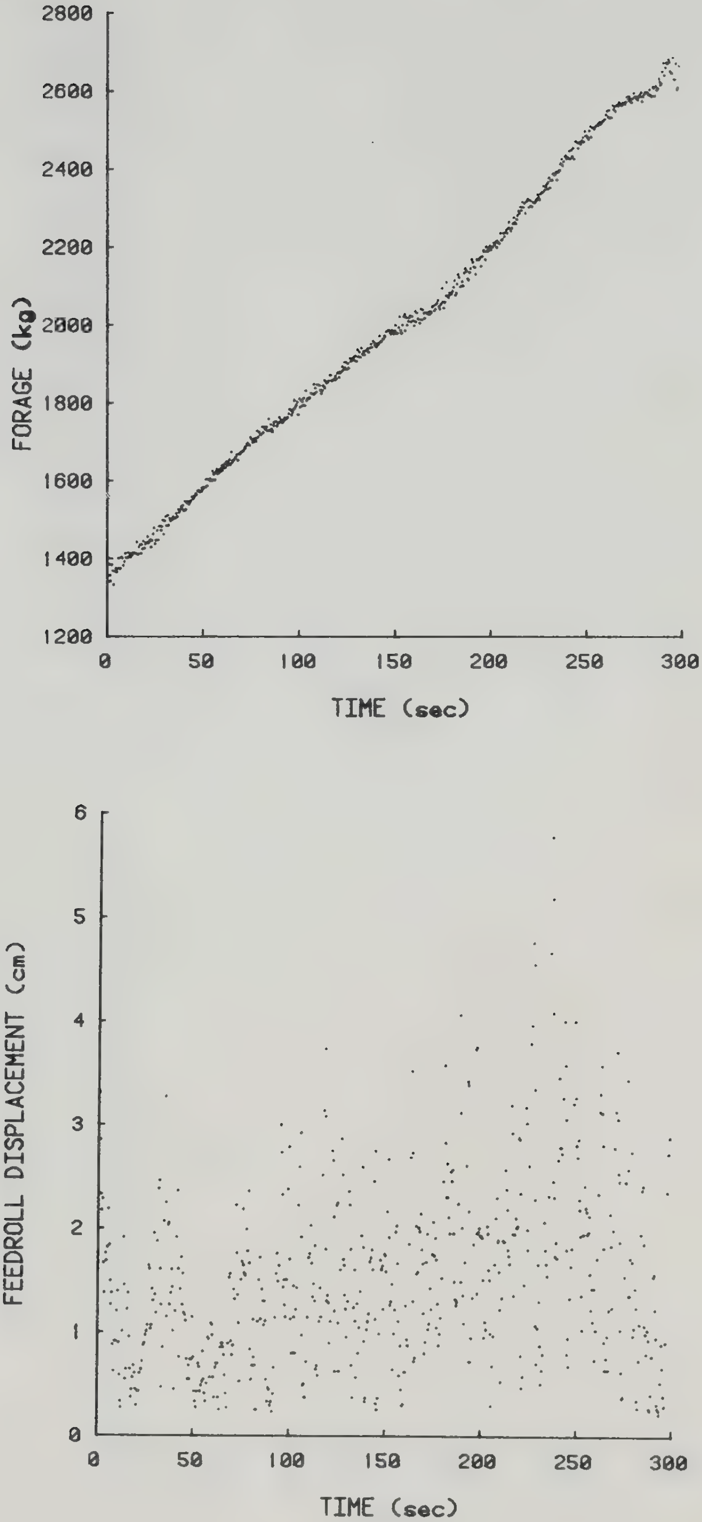
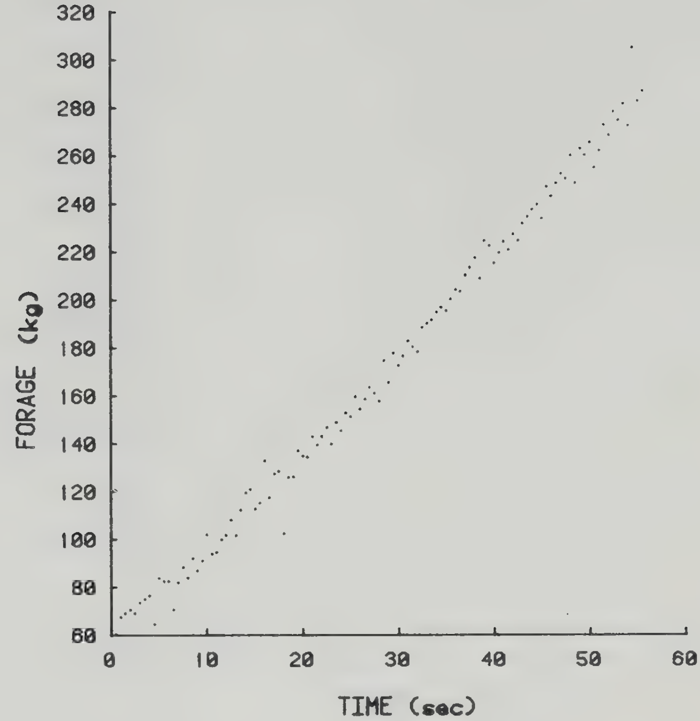


Figure E7 Calibration run #7 with barley : mass of forage in the forage wagon and feedroll displacement versus time.



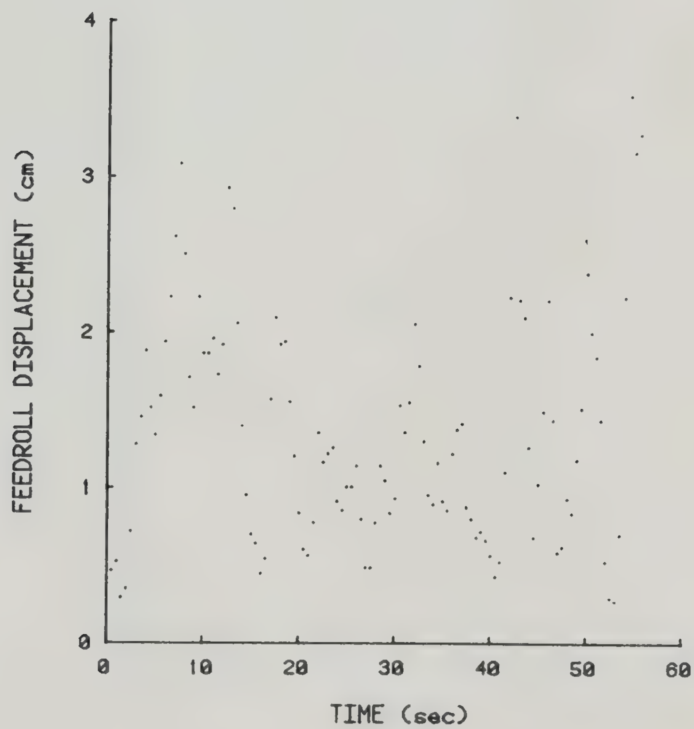
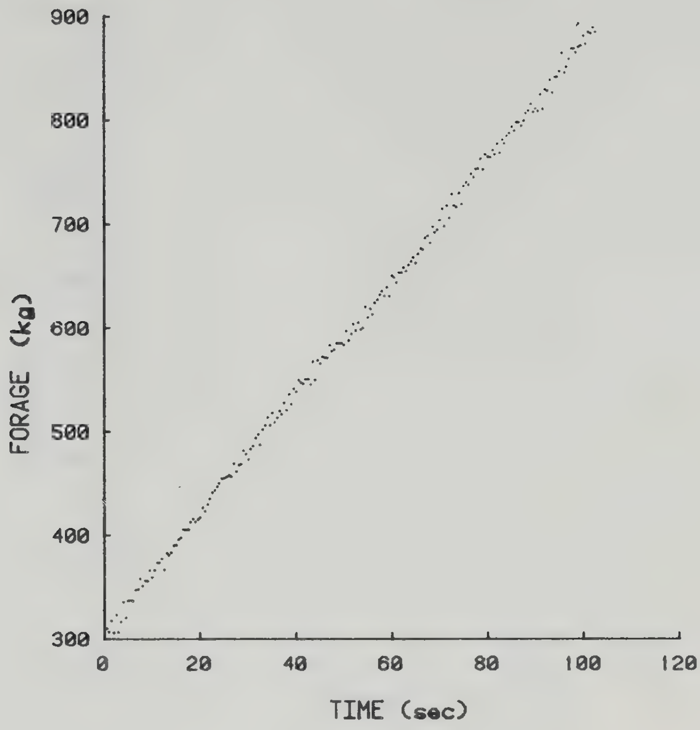


Figure E8 Calibration run #8 with barley : mass of forage in the forage wagon and feedroll displacement versus time.



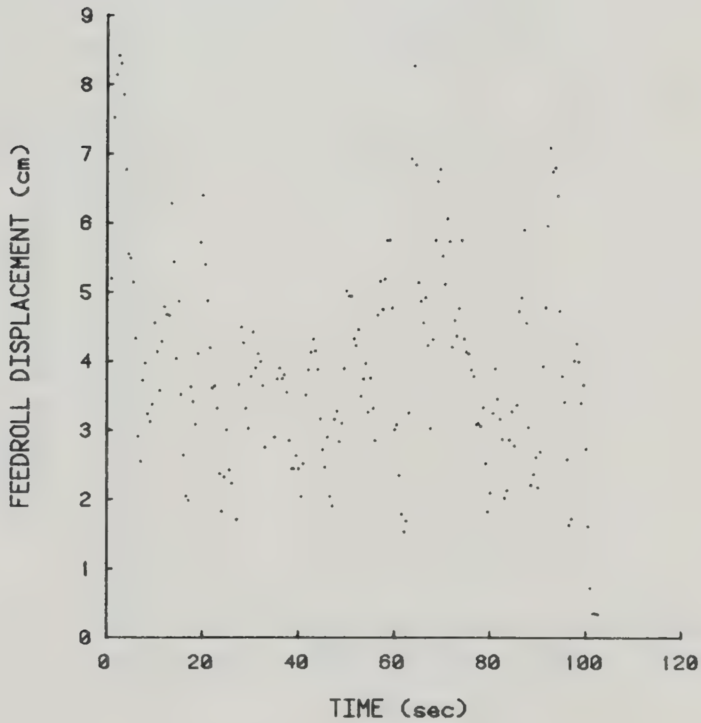


Figure E9 Calibration run #9 with barley : mass of forage in the forage wagon and feedroll displacement versus time.

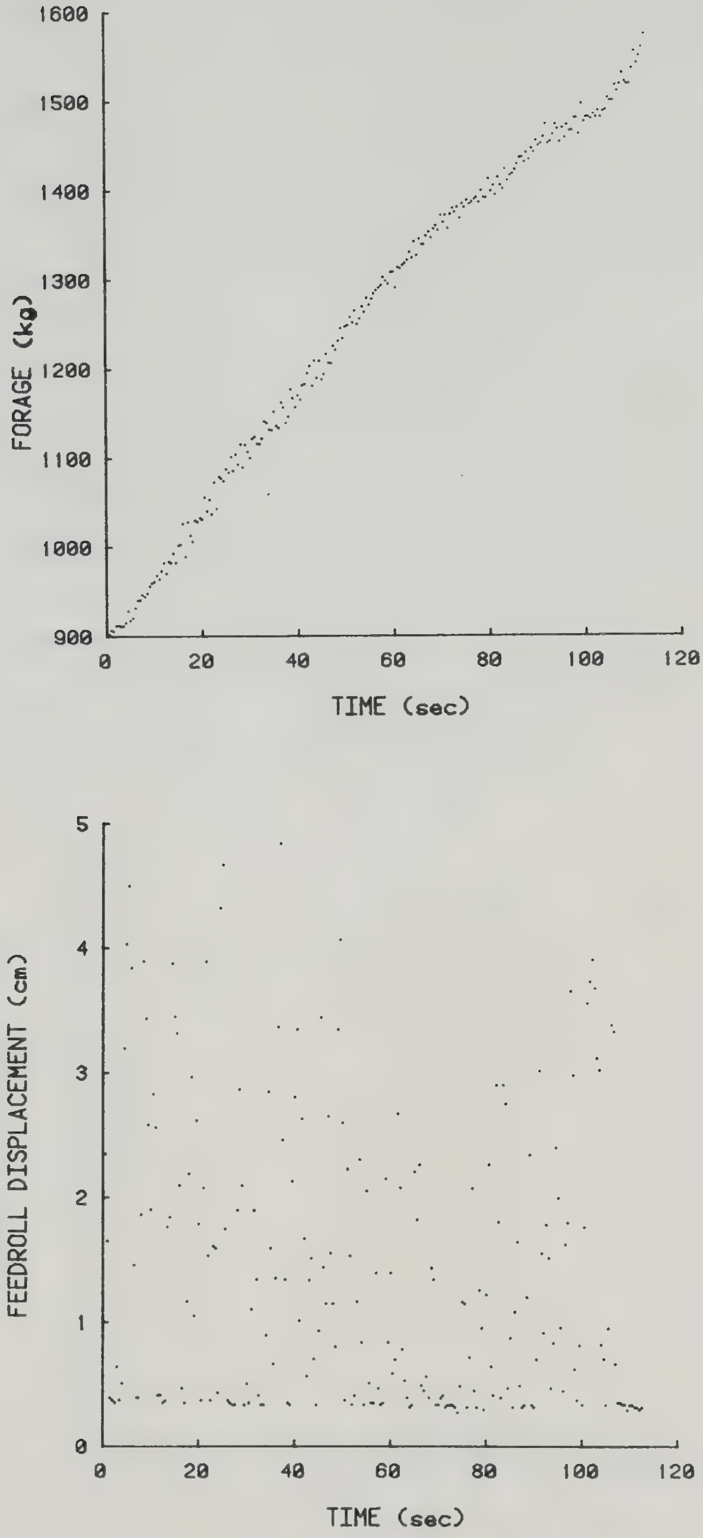
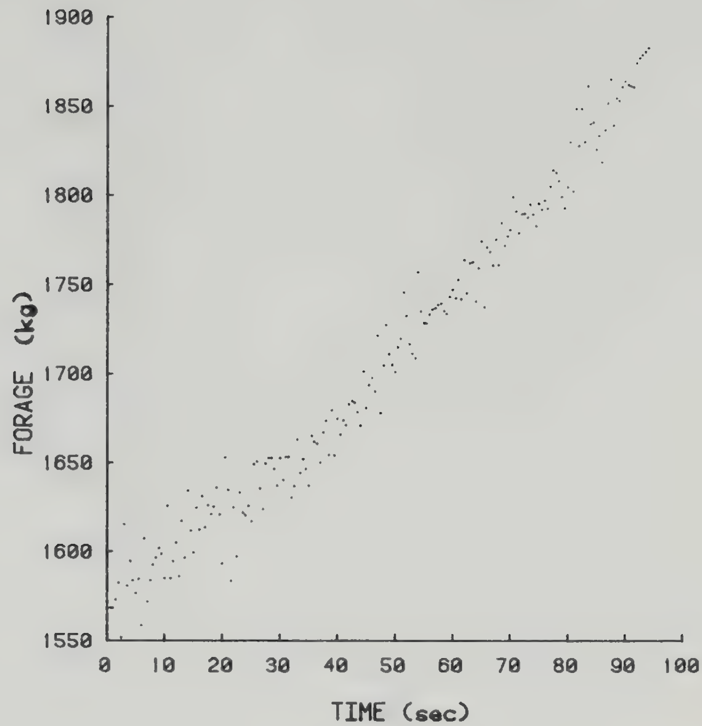


Figure E10 Calibration run #10 with barley : mass of forage in the forage wagon and feedroll displacement versus time.



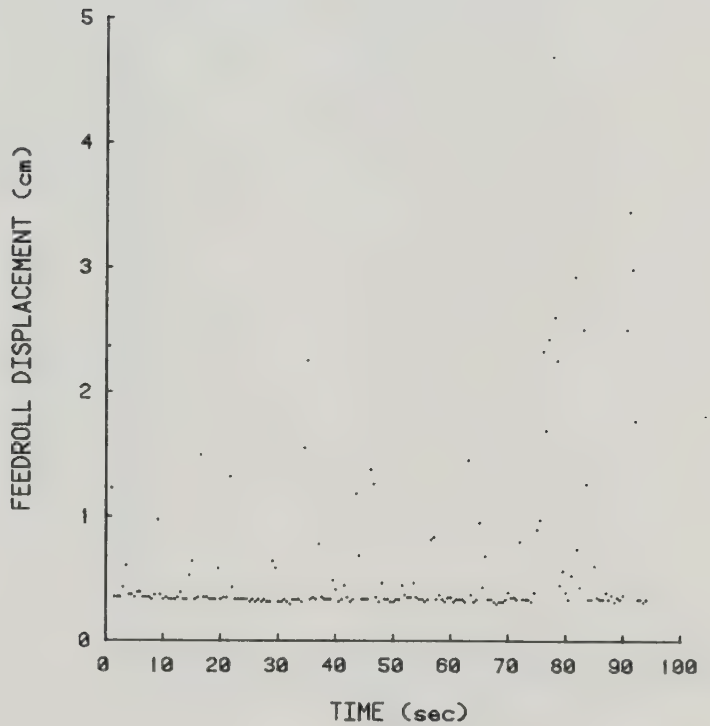
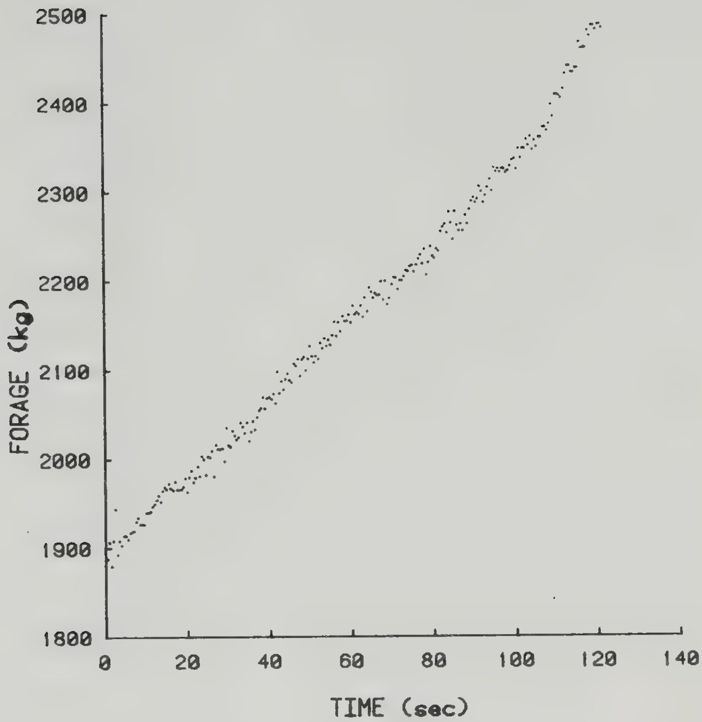


Figure E11 Calibration run #11 with barley : mass of forage in the forage wagon and feedroll displacement versus time.



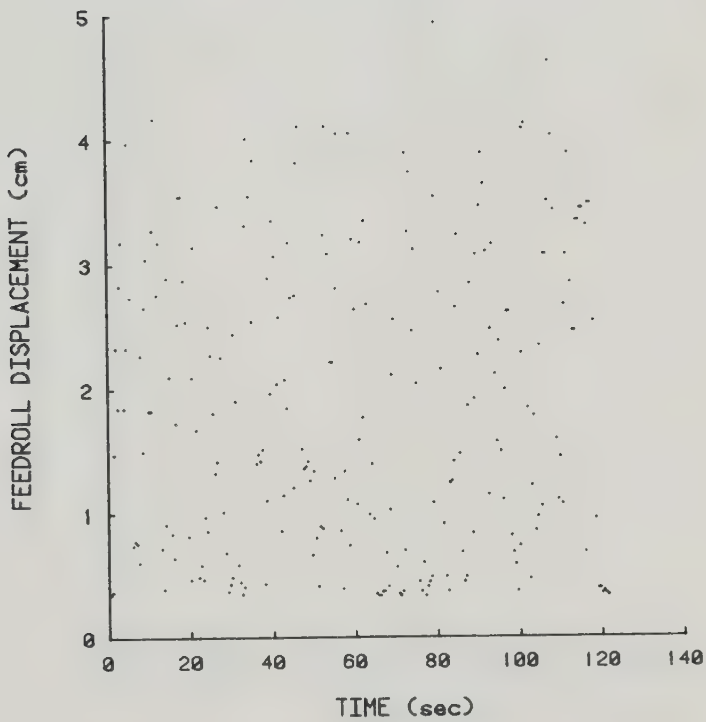


Figure E12 Calibration run #12 with barley : mass of forage in the forage wagon and feedroll displacement versus time.

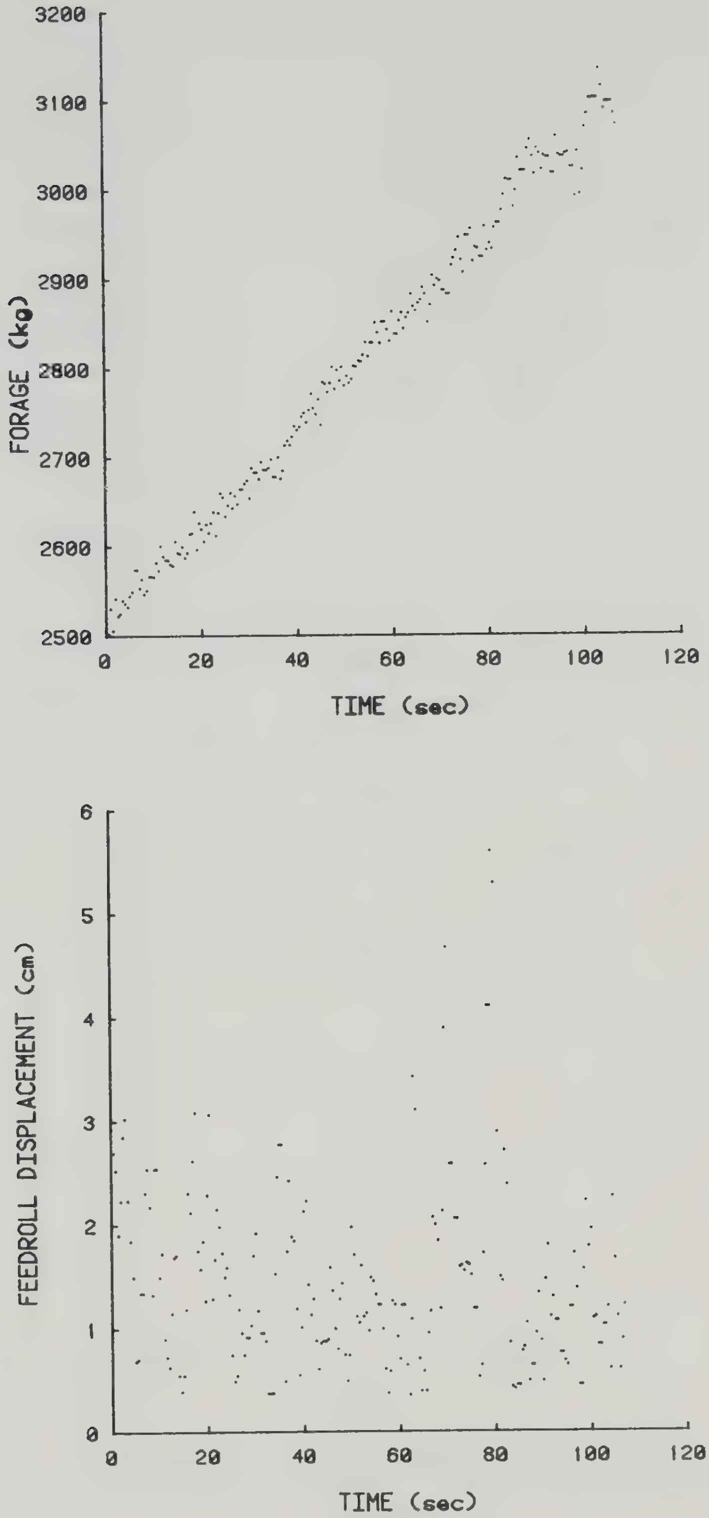


Figure E13 Calibration run #13 with barley : mass of forage in the forage wagon and feedroll displacement versus time.

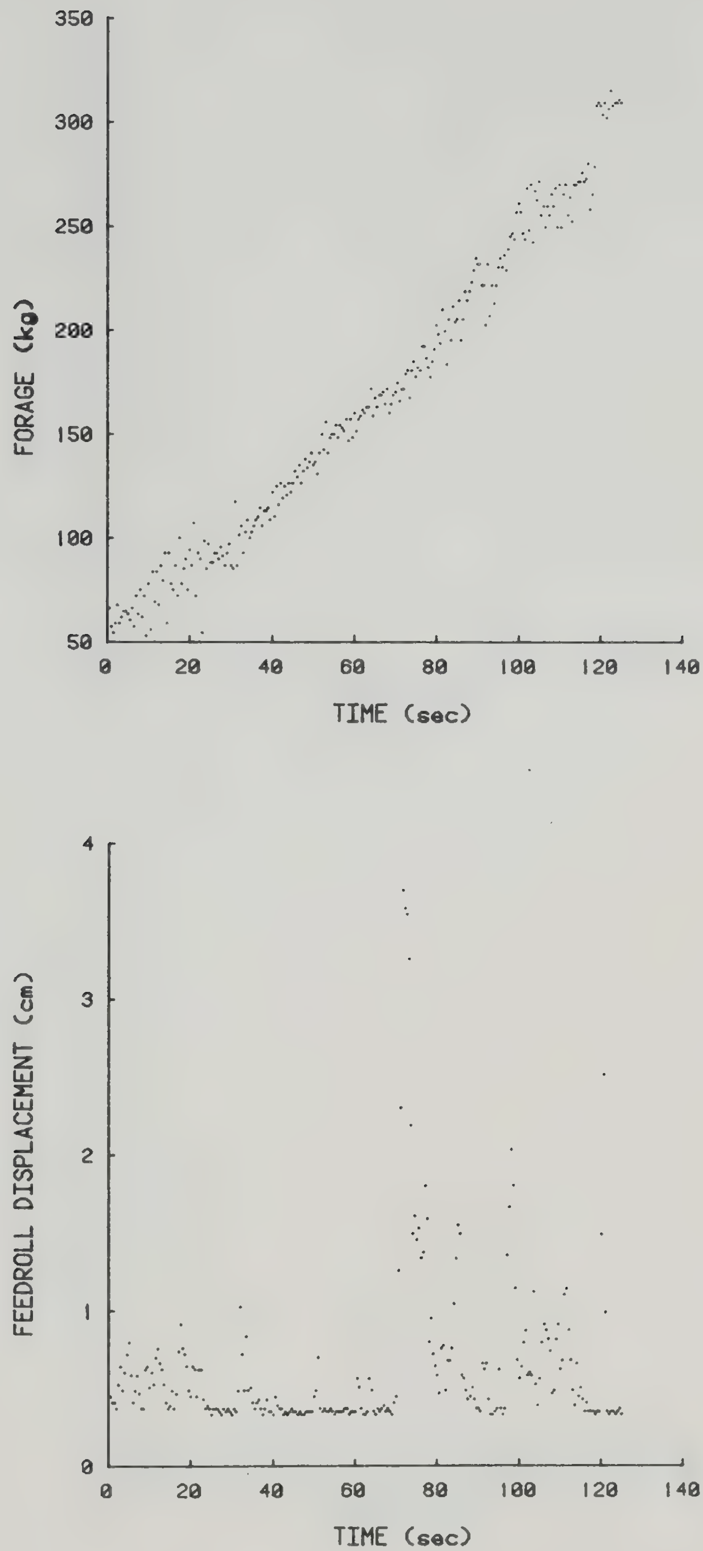


Figure E14 Calibration run #14 with barley : mass of forage in the forage wagon and feedroll displacement versus time.

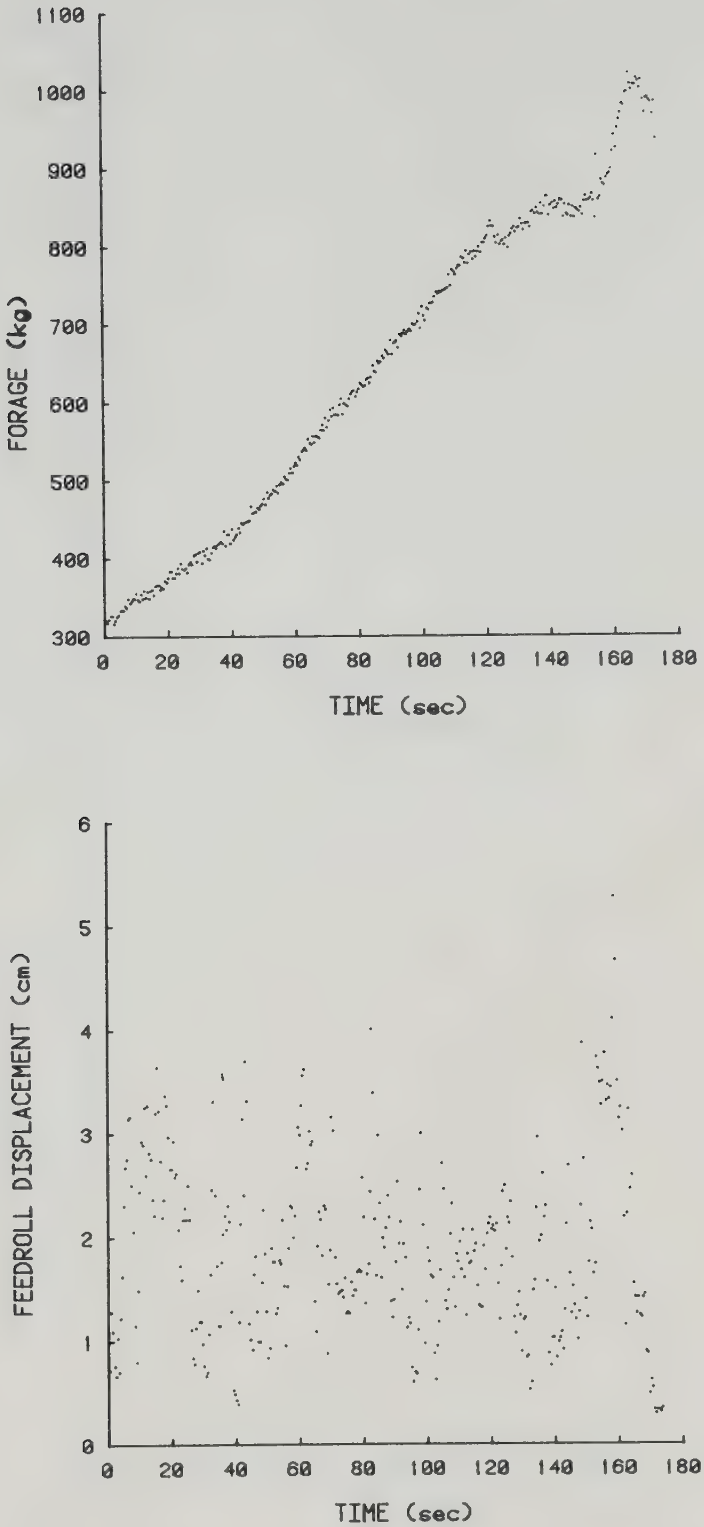
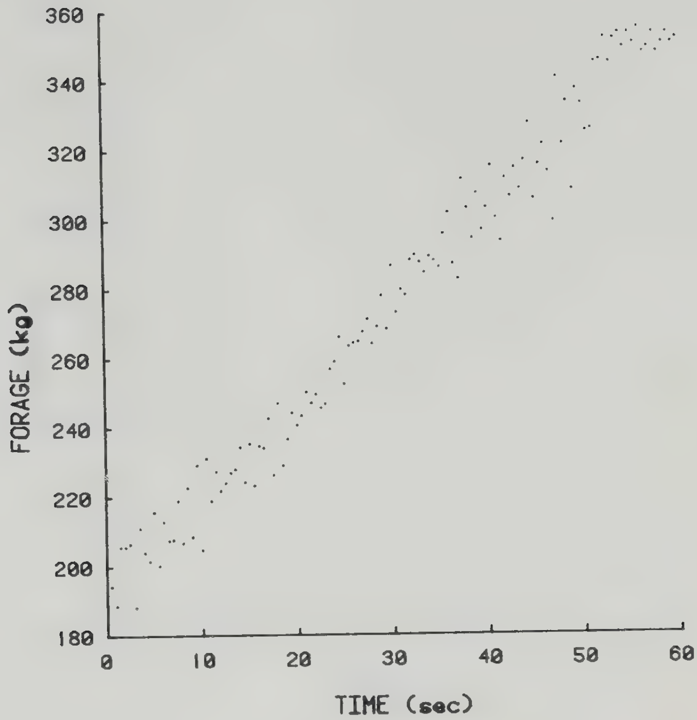


Figure E15 Calibration run #15 with barley : mass of forage in the forage wagon and feedroll displacement versus time.



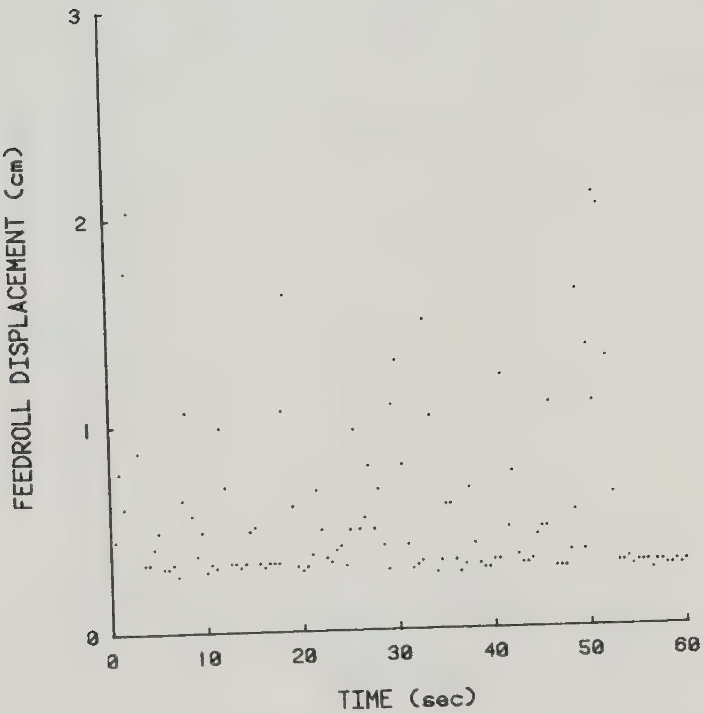


Figure E16 Calibration run #1 with alfalfa : mass of forage in the forage wagon and feedroll displacement versus time.

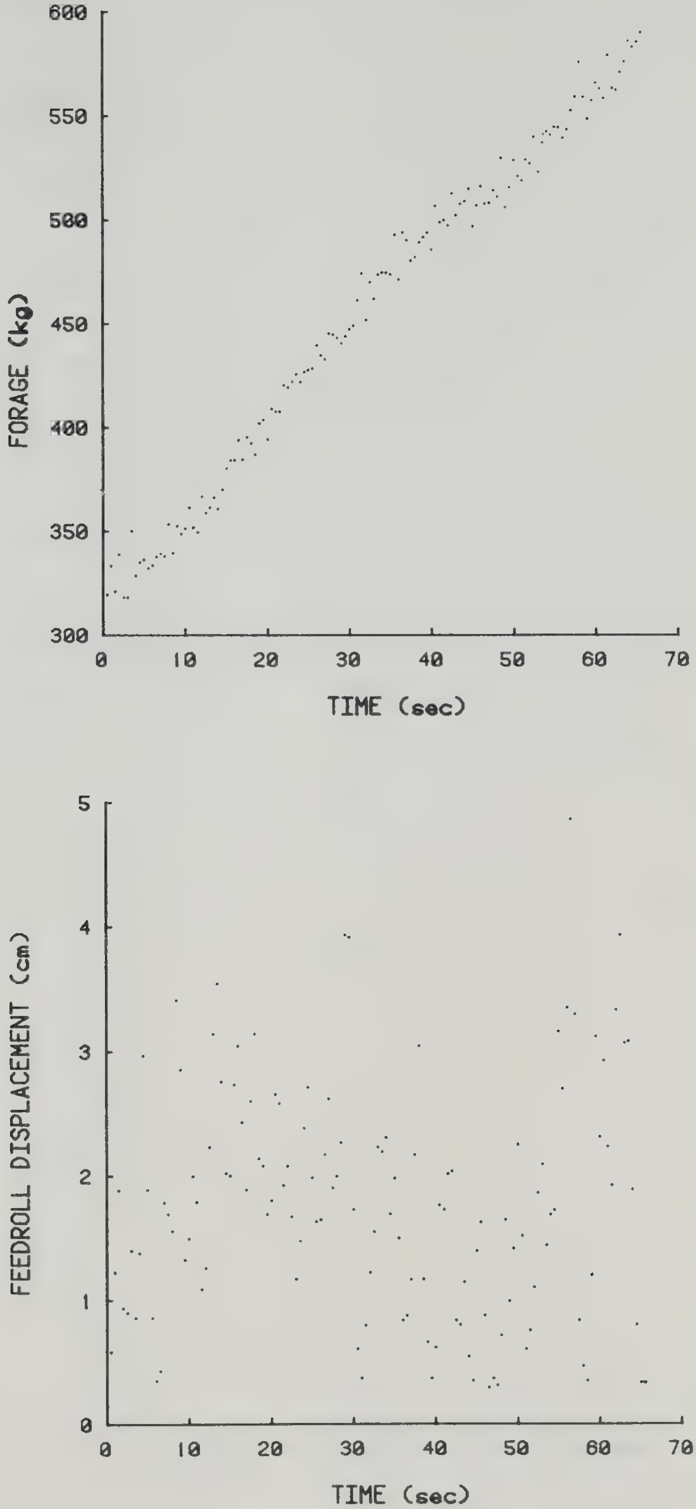


Figure E17 Calibration run #2 with alfalfa : mass of forage in the forage wagon and feedroll displacement versus time.

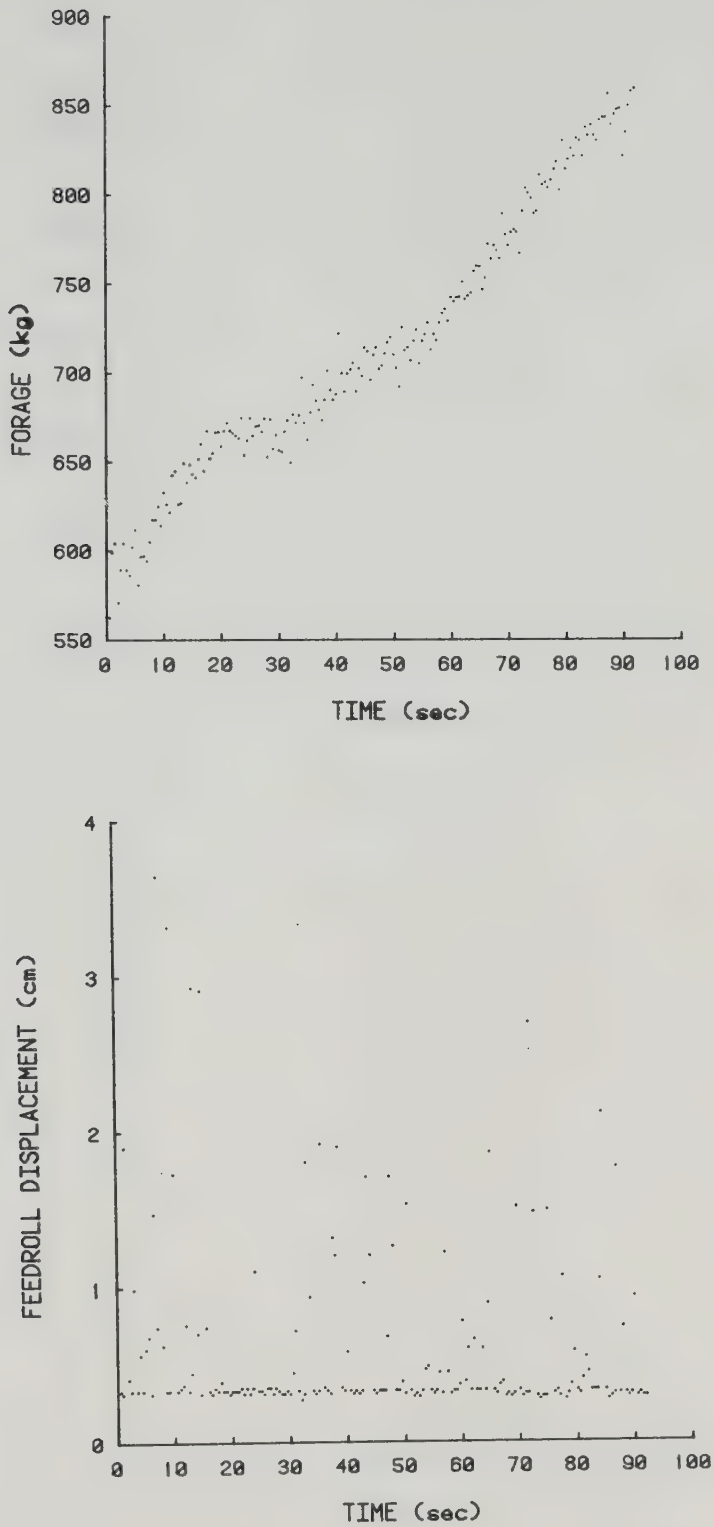
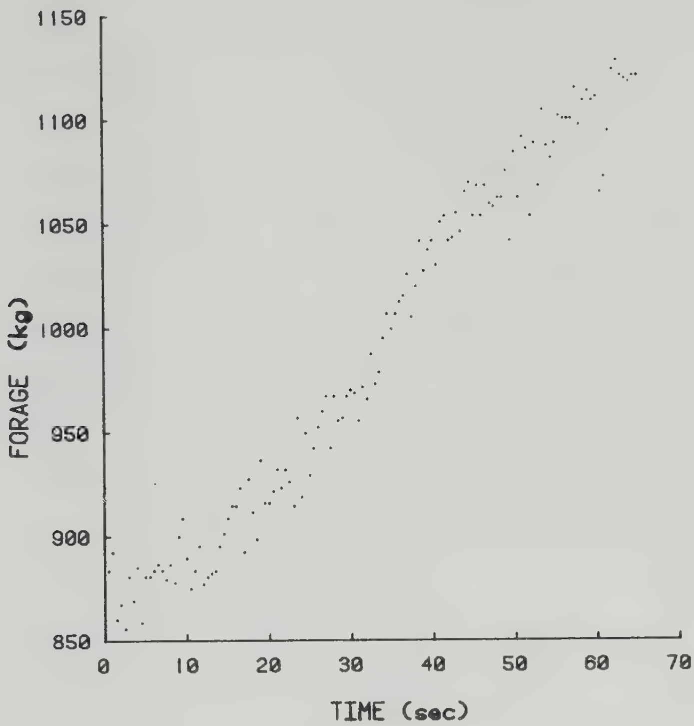


Figure E18 Calibration run #3 with alfalfa : mass of forage in the forage wagon and feedroll displacement versus time.



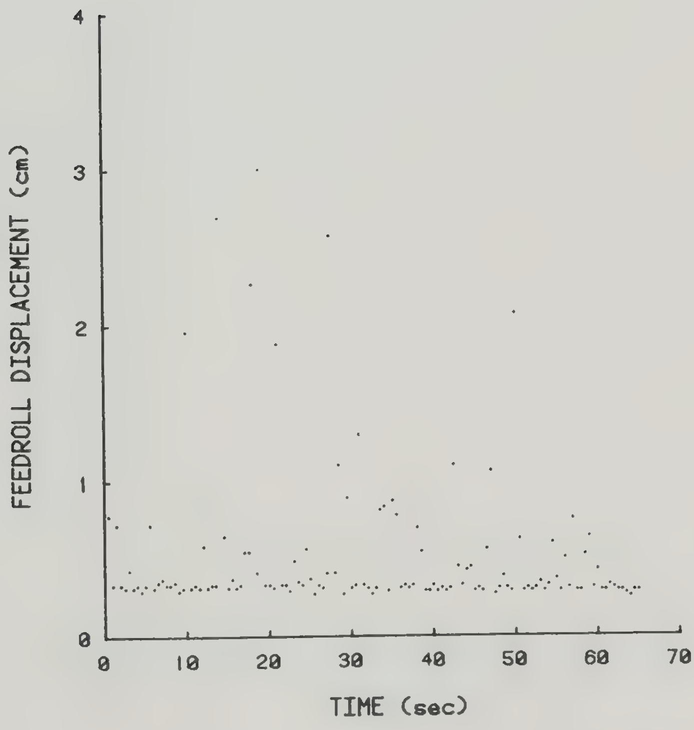
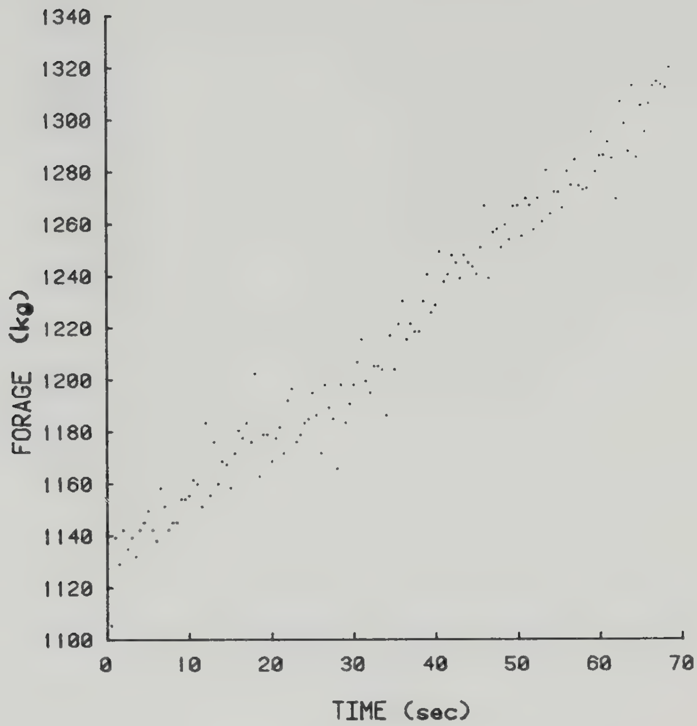


Figure E19 Calibration run #4 with alfalfa : mass of forage in the forage wagon and feedroll displacement versus time.



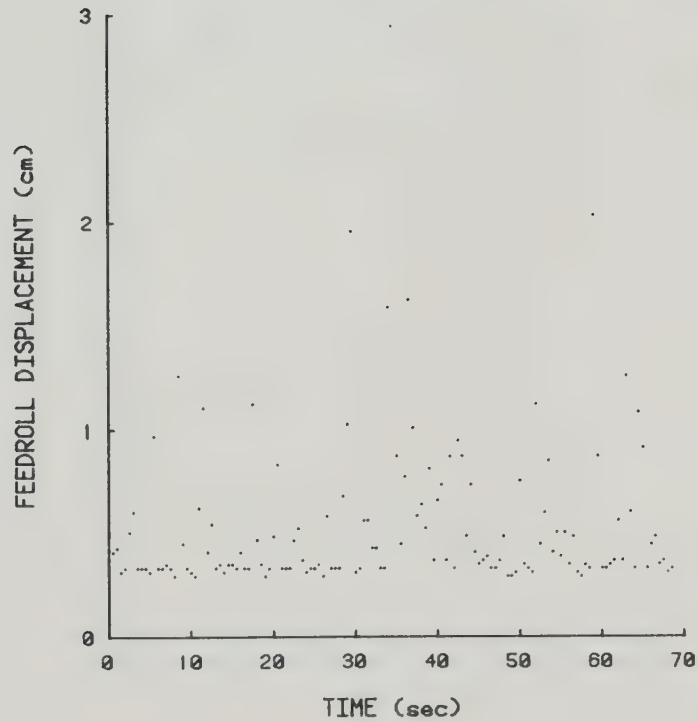


Figure E20 Calibration run #5 with alfalfa : mass of forage in the forage wagon and feedroll displacement versus time.

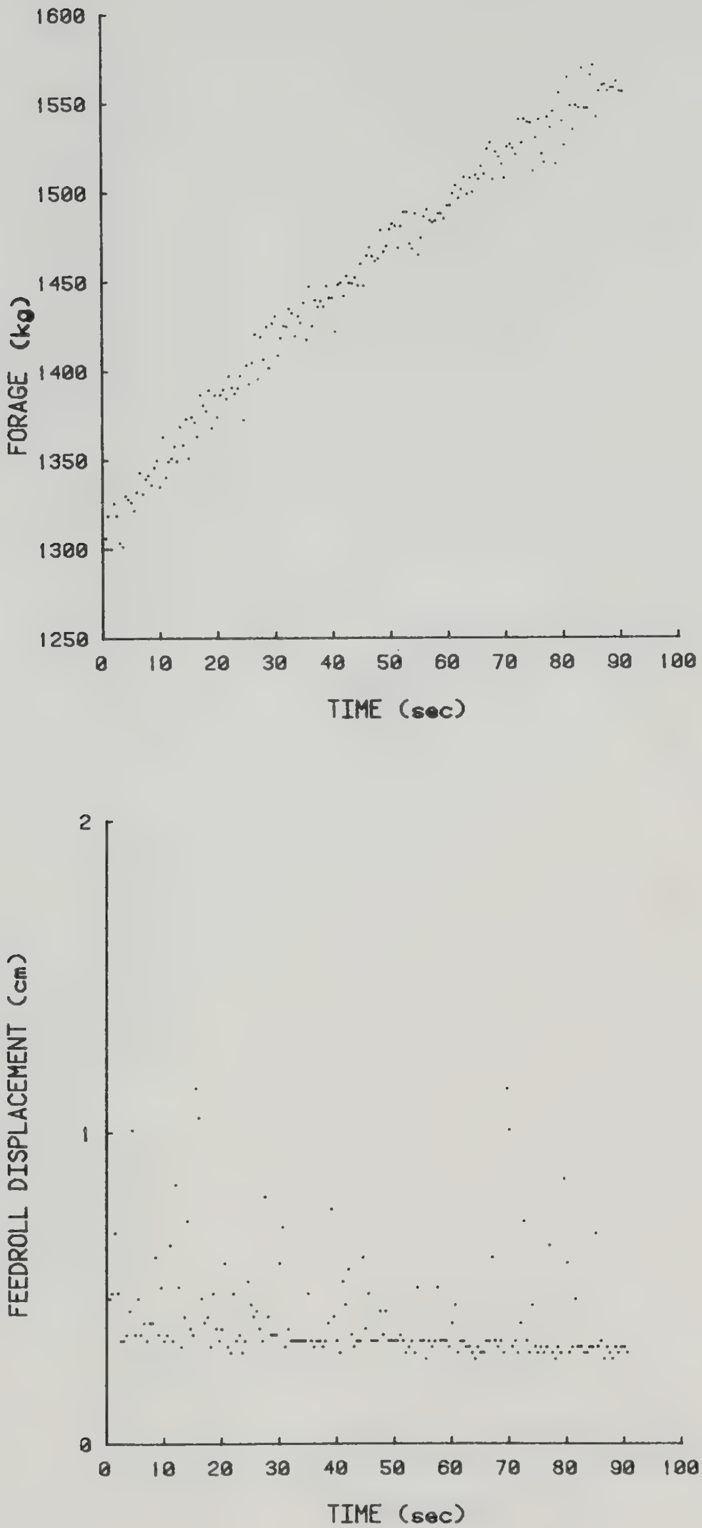
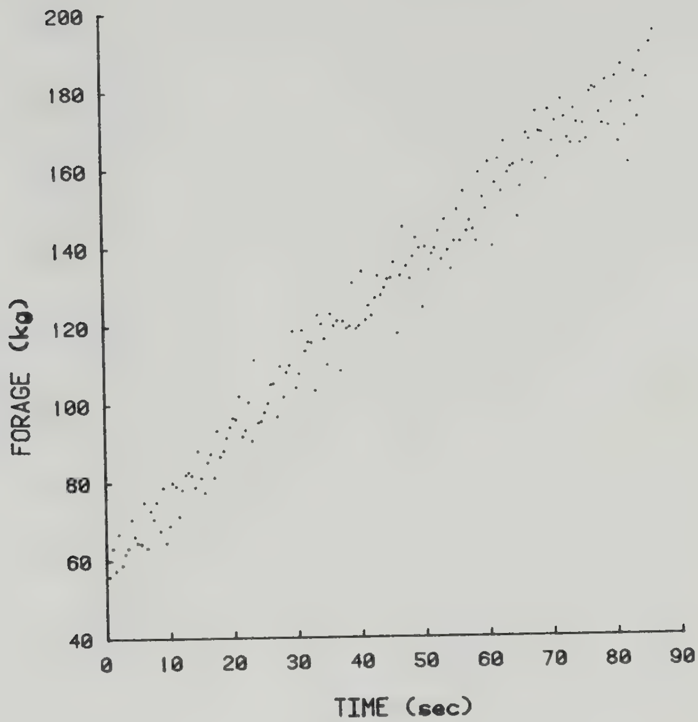


Figure E21 Calibration run #6 with alfalfa : mass of forage in the forage wagon and feedroll displacement versus time.



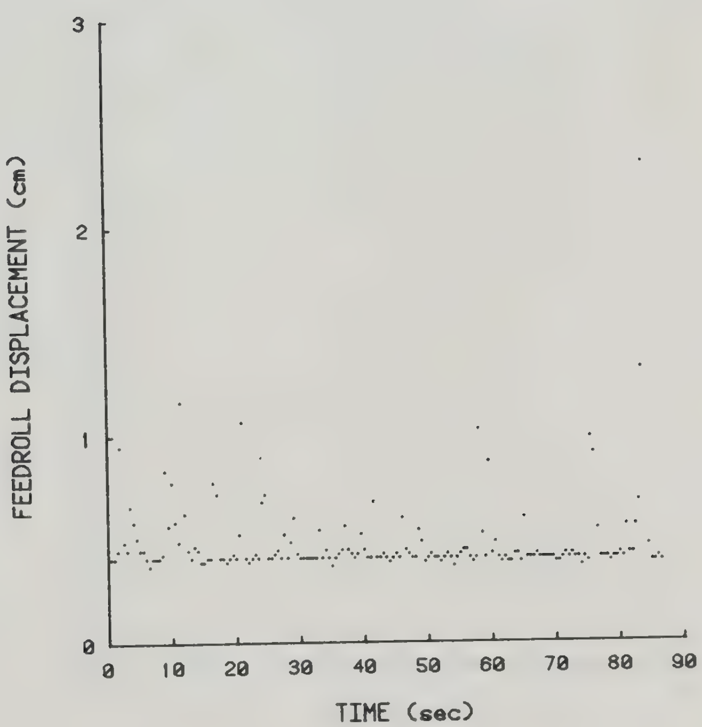
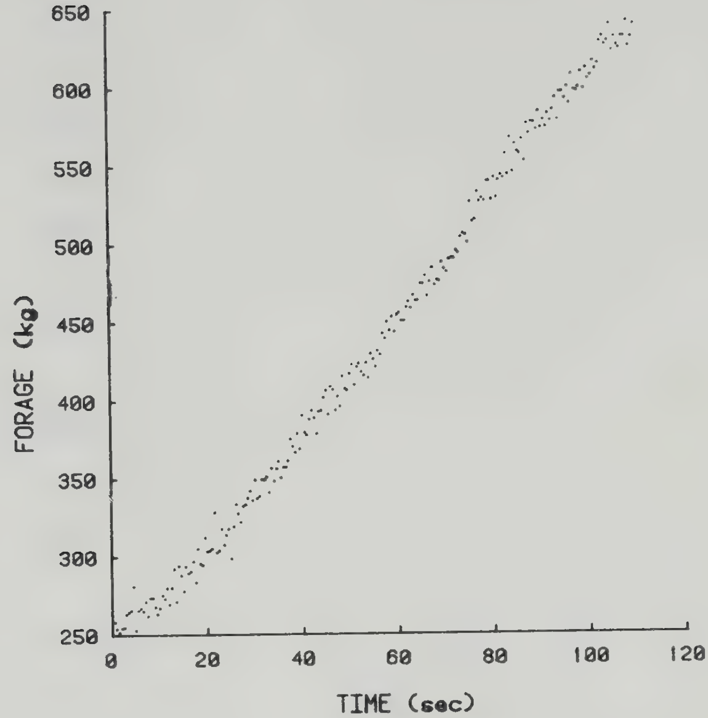


Figure E22 Calibration run #7 with alfalfa : mass of forage in the forage wagon and feedroll displacement versus time.



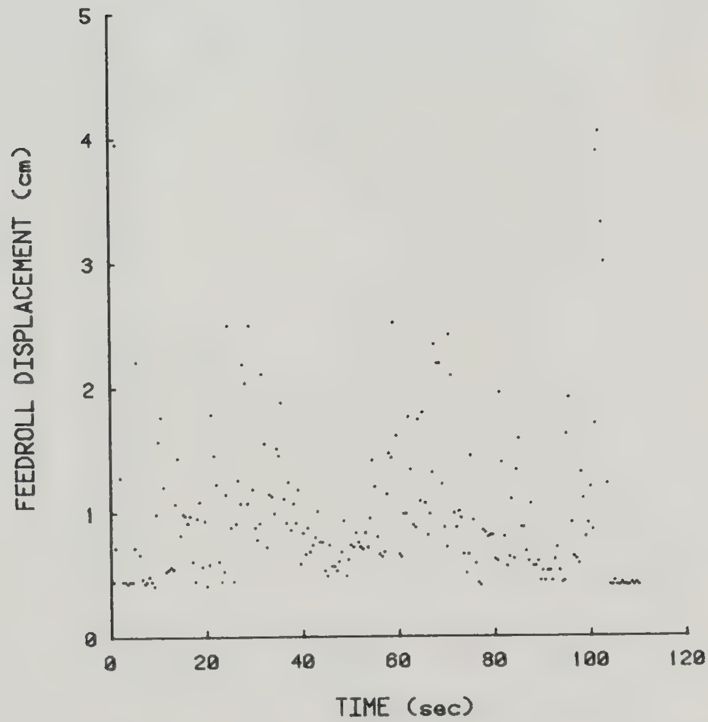


Figure E23 Calibration run #8 with alfalfa : mass of forage in the forage wagon and feedroll displacement versus time.

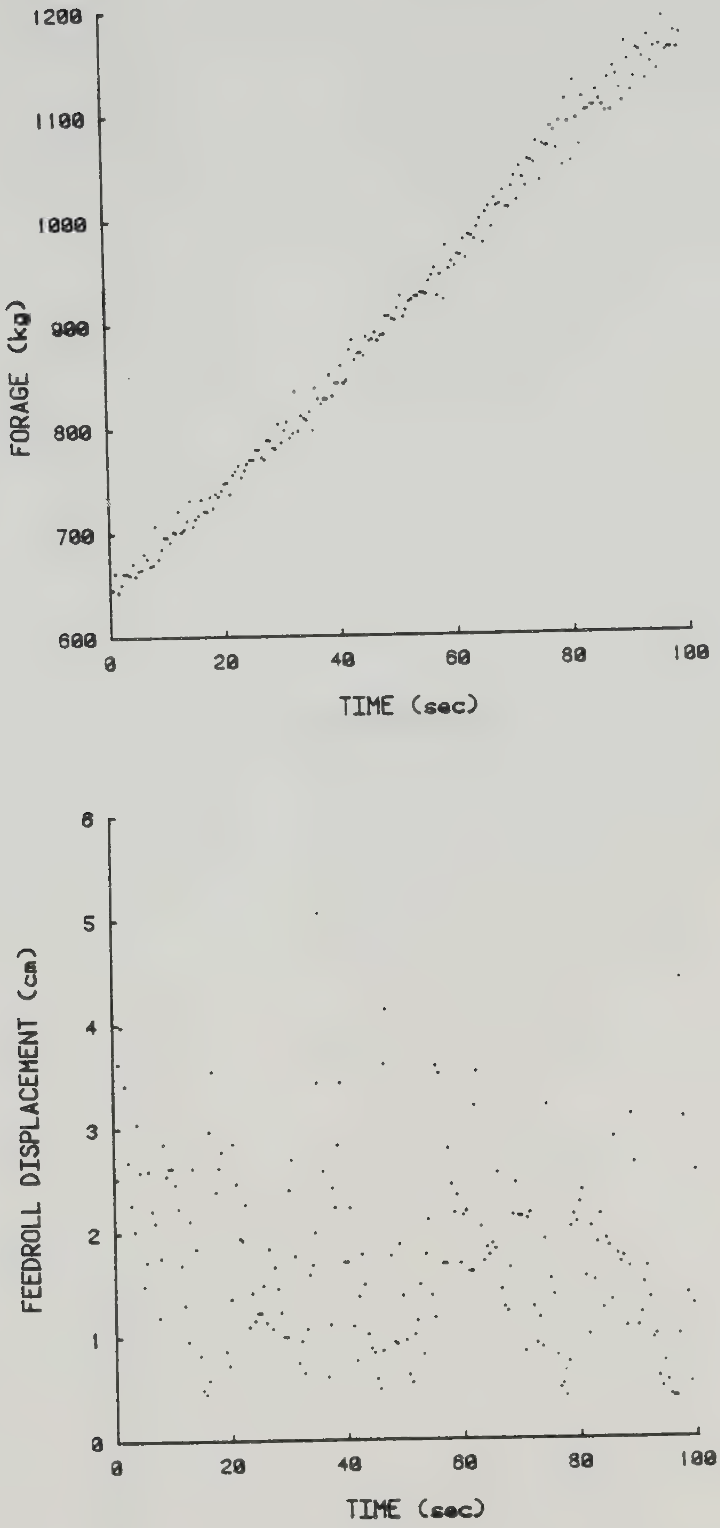
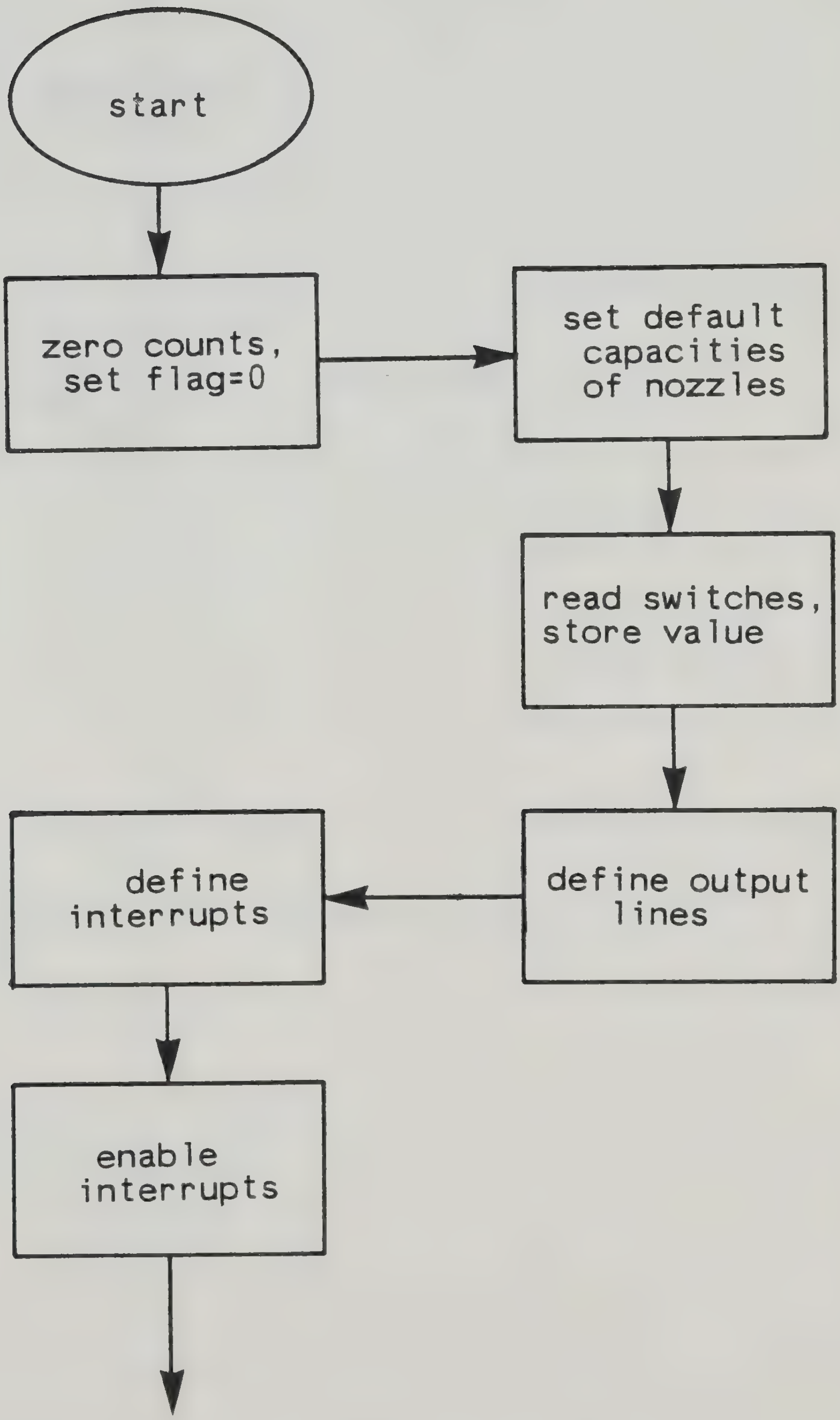
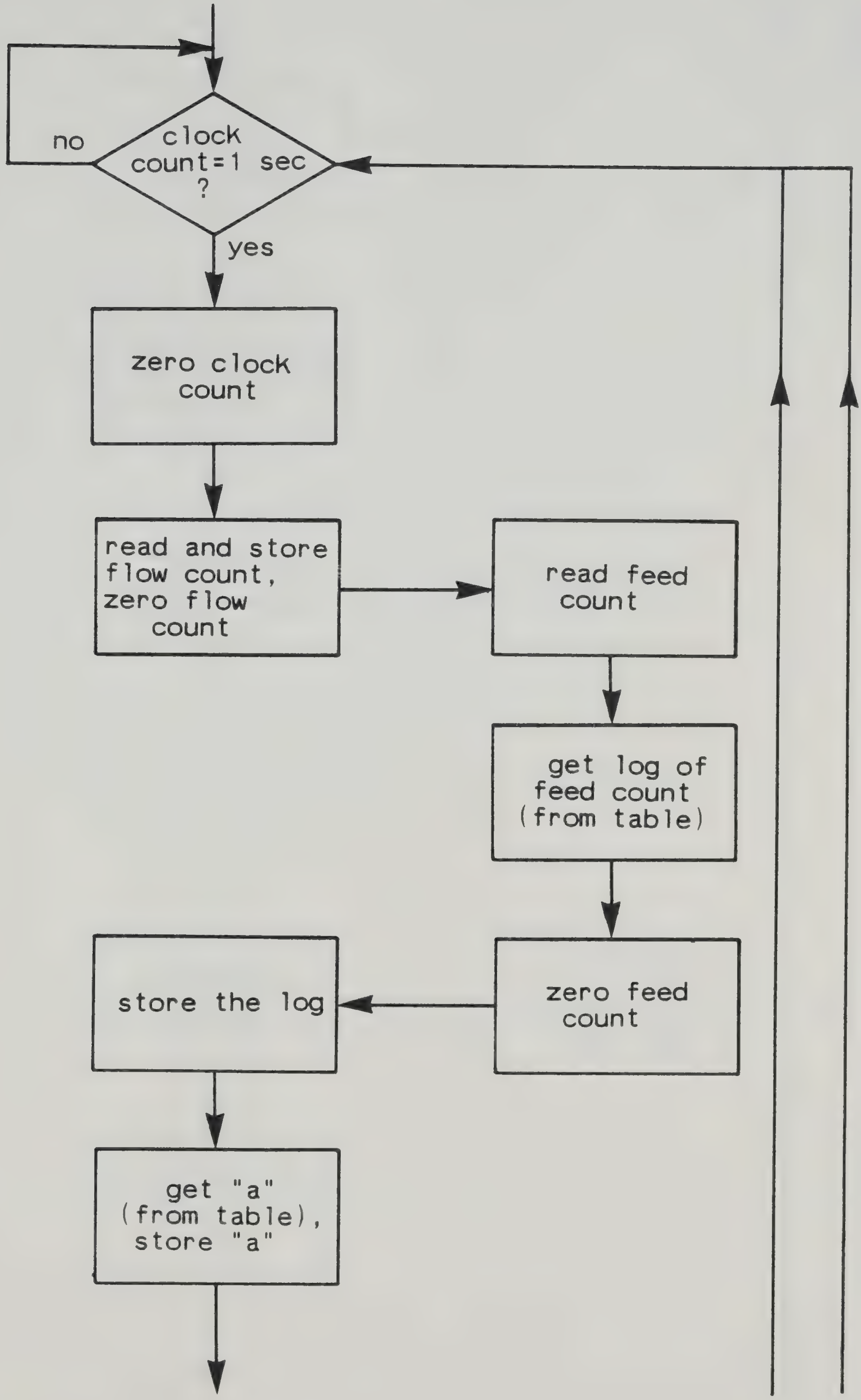


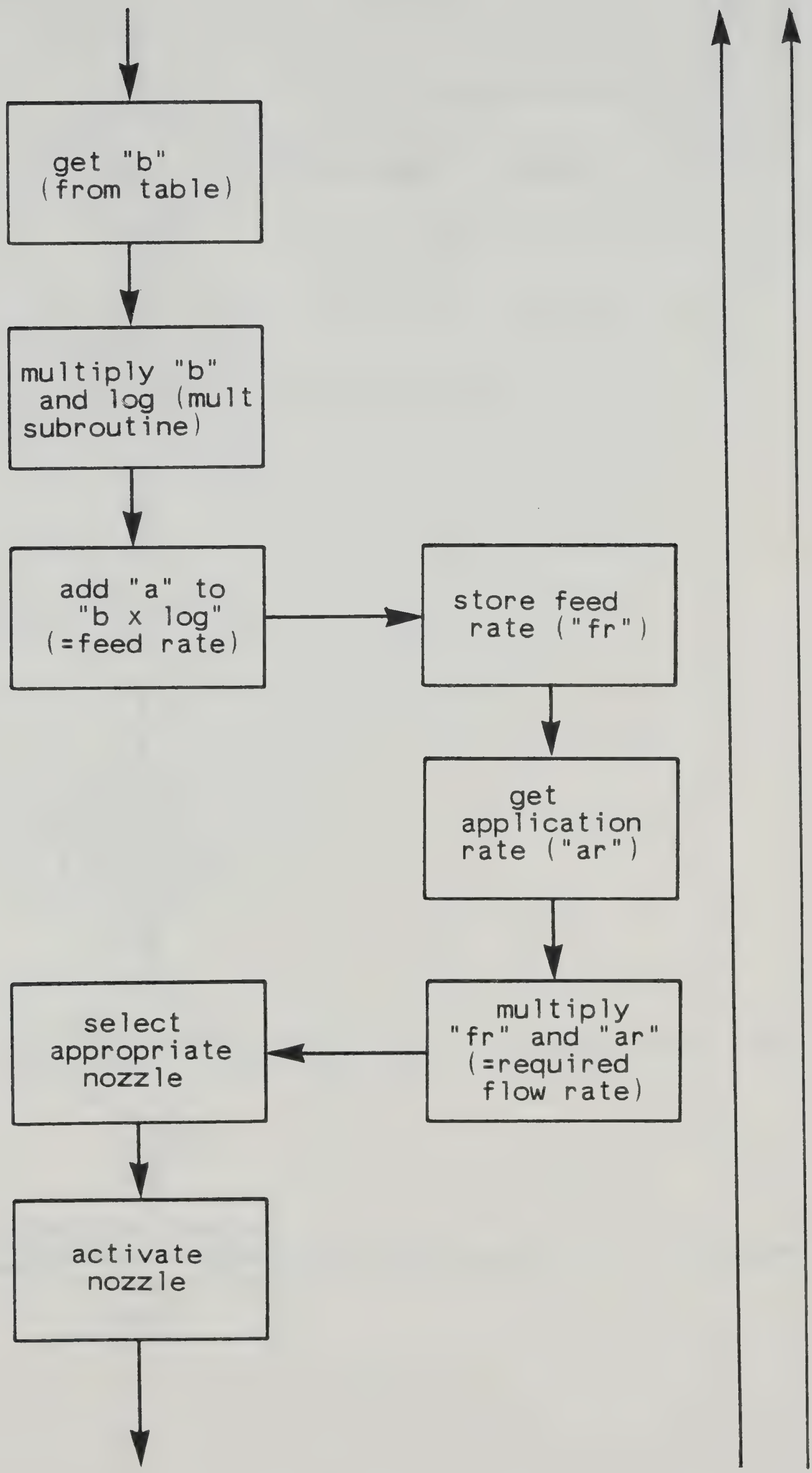
Figure E24 Calibration run #9 with alfalfa : mass of forage in the forage wagon and feedroll displacement versus time.

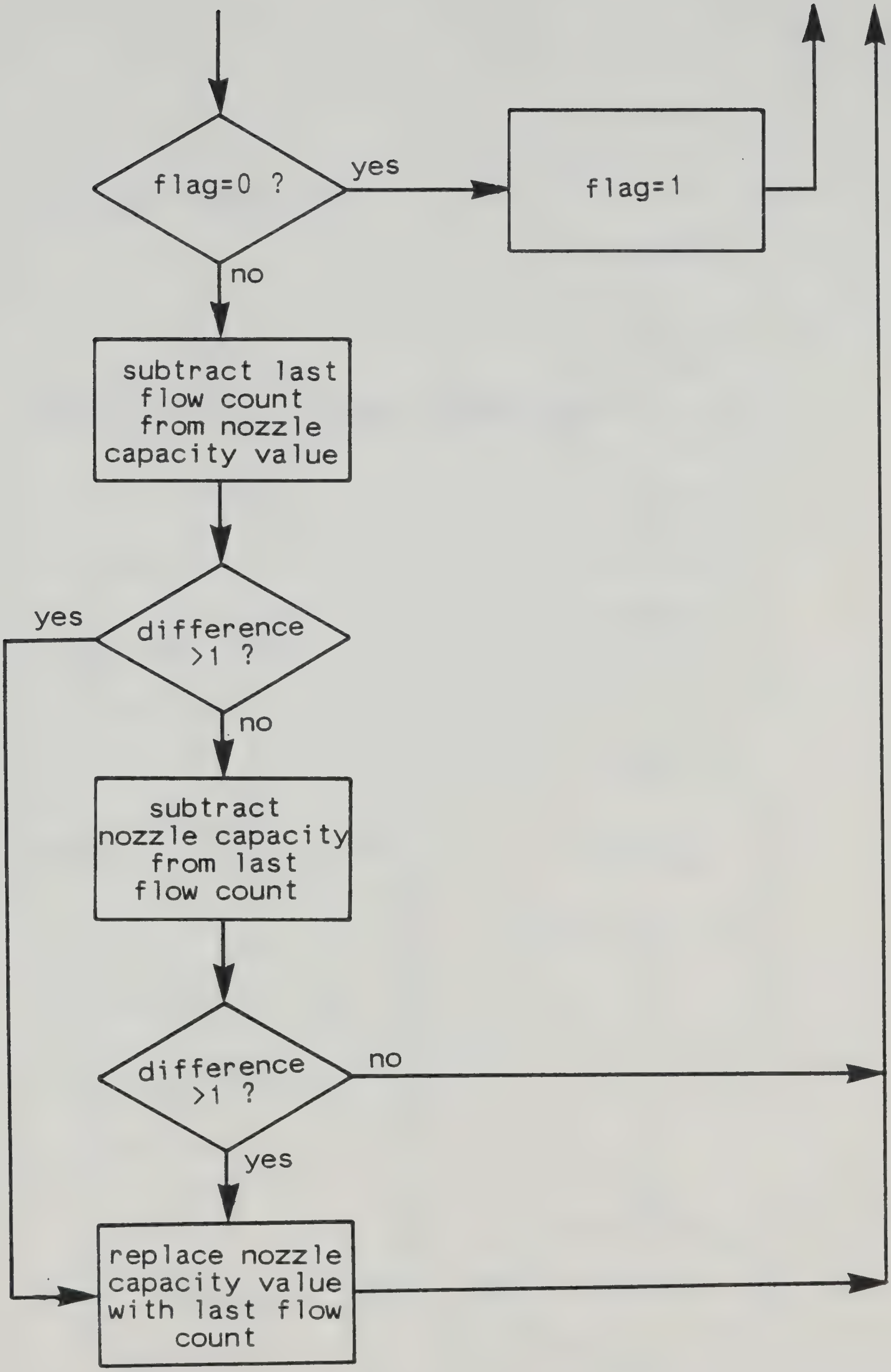
APPENDIX F

Flowchart of the microprocessor program for chemical application control.

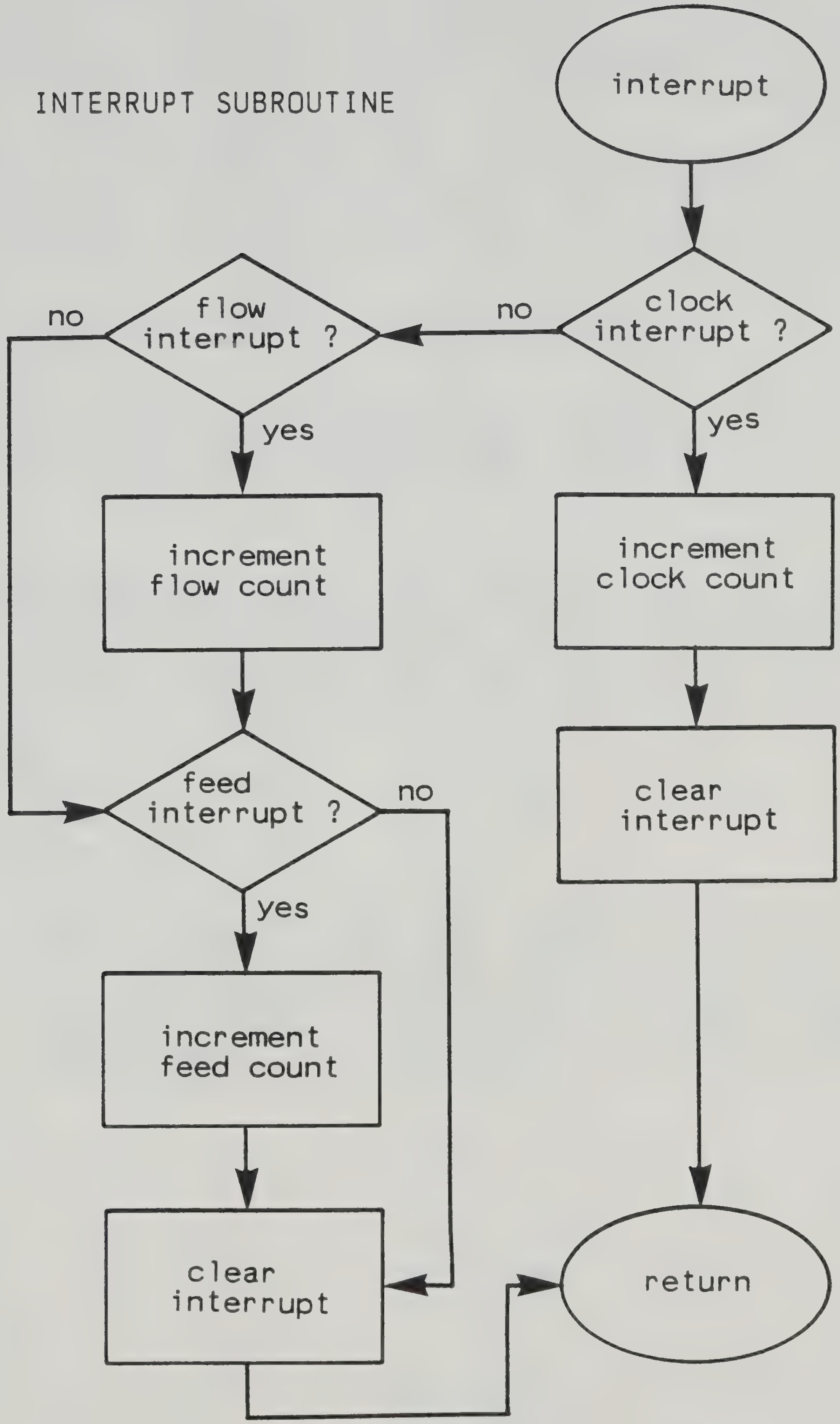



no
clock count=1 sec ?
yes
zero clock count
read and store flow count, zero flow count
read feed count
get log of feed count (from table)
zero feed count
store the log
get "a" (from table), store "a"


get "b" (from table)
multiply "b" and log (mult subroutine)
add "a" to "b x log" (=feed rate)
store feed rate ("fr")
get application rate ("ar")
multiply "fr" and "ar" (=required flow rate)
select appropriate nozzle
activate nozzle


flag=0 ?
yes
flag=1
no
subtract last flow count from nozzle capacity value
yes
difference >1 ?
no
subtract nozzle capacity from last flow count
difference >1 ?
no
yes
replace nozzle capacity value with last flow count

INTERRUPT SUBROUTINE



MICROPROCESSOR PROGRAM FOR CHEMICAL APPLICATION CONTROL

The eight switches to be set by the operator are connected to PIA lines A0 to A7. The value entered on four of the switches represents the application rate, the value entered on the other four switches represents the type of harvest run (ie. crop and harvester).
The output to the power amplifier and then to the solenoids is on PIA lines B0 to B3.
The clock is connected to PIA interrupt line CA1.
The clock is 60 Hz; therefore, one second is 60 pulses.
The flowmeter is connected to PIA interrupt line CB1.
The feed rate sensor is connected to PIA interrupt line CB2.

Memory addresses $0000 to $007F are RAM.
Memory addresses $0800 to $0FFF are EPROM.

PIA data/direction A address (DDA) = $0400
PIA control/status A address (CSA) = $0401
PIA data/direction B address (DDB) = $0402
PIA control/status B address (CSB) = $0403

This program has been written for four nozzles, with increasing capacities from nozzle #1 through nozzle #4. The output values which will activate the singular nozzle or nozzle combinations provided for in this program are:

```
nozzle 1 :     0001 (binary) = 1 (decimal)
nozzle 2 :     0010          = 2
nozzle 3 :     0100          = 4
nozzle 4 :     1000          = 8
nozzles 1+3 : 0101          = 5
nozzles 2+3 : 0110          = 6
```

Note: this program has not been calibrated to a specific set of nozzles, flow rate sensor, or feed rate sensor. The values corresponding to a particular nozzle size, flow rate sensor, or feed rate sensor, and the equation constants for different harvest conditions have been replaced by dashes (--) in this program.

Program Listing :

```
ADDRESS  OPCODES   NAME   MNEMONICS        COMMENTS
*
* INITIALIZE SECTION
*
* Start program at location $0850.
* Use memory locations $0050 to $007F for data and buffers.
*
$0050              CLOCK  RMB 1            Clk pulse count.
$0051              FLOW   RMB 1            Flowmeter count.
$0052              FEED   RMB 1            Feed rate sensor
                                           pulse count.
$0053              CROP   RMB 1            Type # of harvest
                                           run (switches).
$0054              APPL   RMB 1            Applic rate #
                                           (switches).
$0055              CHOIC  RMB 1            Nozzle # chosen.
$0056              LACHO  RMB 2            Nozzle # used in
                                           previous second.
$0058              LAFLO  RMB 1            "FLOW" count in
                                           the previous sec.
$0059              NOZZ1  RMB 1            Capacity nozz 1.
$005A              NOZZ2  RMB 1            Capacity nozz 2.
$005B              NOZZ3  RMB 1            Capacity nozz 3.
$005C              NOZZ4  RMB 1            Capacity nozz 4.
$005D              NOZZ5  RMB 1            Capac. nozzs 1+3.
$005E              NOZZ6  RMB 1            Capac. nozzs 2+3.
$005F              FIRST  RMB 1            Flag for 1st sec.
$0060              CONA   RMB 1            Temporary storage
$0061              LOG    RMB 1            of values
$0062              MULT1  RMB 1            calculated.
$0063              MULT2  RMB 1
$0064              MULT3  RMB 1
$0065              FRAT   RMB 1
*
* Set the initial values.
*
$0850    7F 0050          CLR CLOCK        Zero clock count.
$0853    7F 0051          CLR FLOW         Zero flow count.
$0856    7F 0052          CLR FEED         Zero feed count.
$0859    7F 005F          CLR FIRST        Zero flag.
$085C    01               NOP
$085D    01               NOP
$085E    01               NOP
$085F    86 --            LDA A #$--       Store capacity
$0861    B7 0059          STA A NOZZ1      of nozzle 1.
$0864    86 --            LDA A #$--
$0866    B7 005A          STA A NOZZ2
$0869    86 --            LDA A #$--
$086B    B7 005B          STA A NOZZ3
$086E    86 --            LDA A #$--
$0870    B7 005C          STA A NOZZ4
$0873    86 --            LDA A #$--
```

```
$0875    B7 005D          STA A NOZZ5
$0878    86 --            LDA A #$--
$087A    B7 005E          STA A NOZZ6
$087D    01               NOP
$087E    01               NOP
$087F    01               NOP
*
* Read the eight switches and store the value.
*
$0880    7F 0401          CLR CSA        Specify PIA lines
$0883    7F 0400          CLR DDA        A0 to A7 as
$0886    86 04            LDA A #$04     input.
$0888    B7 0401          STA A CSA
$088B    86 0F            LDA A #$0F     Read switches,
$088D    B4 0400          AND A DDA      store type # of
$0890    B7 0053          STA A CROP     harvest run.
$0893    86 F0            LDA A #$F0     Read switches,
$0895    B4 0400          AND A DDA      store application
$0898    B7 0054          STA A APPL     rate #.
*
* Define PIA lines B0 to B3 as output.
* Define the feed rate and flow rate interrupts.
*
$089B    7F 0403          CLR CSB        Define PIA lines
$089E    86 0F            LDA A #$0F     B0 to B3 as
$0900    B7 0402          STA A DDB      output.
$0903    86 1F            LDA A #$1F     Define CB1 and
$0905    B7 0403          STA A CSB      CB2 interrupts.
$0908    B6 00            LDA A #$00     Set solenoids
$090A    B7 0402          STA A DDB      initially "off".
$090D    01               NOP
$090E    01               NOP
$090F    01               NOP
*
* Define the clock interrupt.
* Enable all interrupts.
*
$0910    86 03            LDA A #$03     Define CA1
$0912    B7 0401          STA A CSA      interrupt.
$0915    0E               CLI            Enable all
*
* MAIN SECTION
*
* Enter a timing loop of one second.
*
$0916    B6 0050    LOOP  LDA A CLOCK    Loop until the
$0919    81 3C            CMP A #$3C     clock count = 60,
$091B    2C 03            BGE CALC       ie.for 1 second.
$091D    7E 0916          JMP LOOP
*
* Read sensors, jump to subroutines, return to timing loop.
*
$0920    7F 0050    CALC  CLR CLOCK      Zero the clock.
$0923    B6 0051          LDA A FLOW     Read and store
```

```
$0926    B7 0058          STA A LAFLO     flow count, then
$0929    7F 0051          CLR FLOW        zero it.
$092C    B6 0052          LDA A FEED      Read feed count,
$092F    CE 0D00          LDX #$0D00      get the log of
$0932    08        MORE   INX             this value from
$0933    80 01            SUBA #$01       the table.
$0935    24 FC            BCC MORE
$0937    E6 00            LDA B 0,X
$0939    7F 0052          CLR FEED        Zero feed count.
$093C    F7 0061          STA B LOG       Store the log.
$093F    BD 0950          JSR NOZZ        Jump to NOZZ.
$0942    BD 0A16          JSR FLOW        Jump to FLOW.
$0945    7E 0916          JMP LOOP        Go loop again.
$0948    01               NOP
$0949    01               NOP
$094A    01               NOP
$094B    01               NOP
$094C    01               NOP
$094D    01               NOP
$094E    01               NOP
$094F    01               NOP
*
* SUBROUTINE TO DETERMINE FORAGE FEED RATE AND THE
* REQUIRED NOZZLES.
*
* Determine the forage feed rate.
*
$0950    B6 0053   NOZZ   LDA A CROP      For this type #
$0953    CE 0D50          LDX #$0D50      of harvest run,
$0956    08        MOR2   INX             get value of
$0957    80 01            SUB A #$01      eq'n constant "a"
$0959    24 FC            BCC MOR2        from the table.
$095B    E6 00            LDA B 0,X
$095D    F7 0060          STA B CONA      Store  "a".
$0960    B6 0053          LDA A CROP      Get value of
$0963    CE 0D70          LDX #$0D70      eq'n constant
$0966    08        MOR3   INX             "b".
$0967    80 01            SUB A #$01
$0969    24 FC            BCC MOR3
$096B    E6 00            LDA B 0,X
$096D    B6 0061          LDA A LOG       Multiply log and
$0970    BD 0A70          JSR MULT        constant "b".
$0973    F6 0060          LDA B CONA      Add "a" to the
$0976    1B               ABA             result to get
                                          feed rate value.
$0977    B7 0065          STA A FRAT      Store value.
$097A    01               NOP
$097B    01               NOP
$097C    01               NOP
$097D    01               NOP
$097E    01               NOP
$097F    01               NOP
*
* Determine the required chemical flow rate.
```

```
*
$0980    F6 0054          LDA B APPL      For this
$0983    CE 0D90          LDX #$0D90      application rate
$0986    08         MOR4  INX             #, get the value
$0987    80 01            SUB A #$01      of application
$0989    24 FC            BCC MOR4        rate.
$098B    E6 00            LDA B 0,X
$098D    F6 0065          LDA B FRAT      Multiply feed
$0990    BD 0A70          JSR MULT        rate and applic
                                          rate values to
                                          get req'd flow.
*
* Determine which nozzles might be chosen.
*
$0993    B1 0059          CMP A NOZZ1     If flow is less
                                          than nozzle 1
$0996    2E 08            BGT NEXT1       capacity, choose
$0998    CE 0000          LDX #$0000      nozzle 1.
$099B    86 00            LDA A #$00
$099D    7E 0A00          JMP SET         Turn on nozzle
$09A0    B1 005A    NEXT1 CMP A NOZZ2     If flow is
$09A3    2E 08            BGT NEXT2       between capac
$09A5    CE 0001          LDX #$0001      of nozz 1 and 2,
$09A8    86 01            LDA A #$01      go choose 1 or
$09AA    7E 09F0          JMP CHOOS       2.
$09AD    B1 005B    NEXT2 CMP A NOZZ3
$09B0    2E 08            BGT NEXT3
$09B2    CE 0002          LDX #$0002
$09B5    86 02            LDA A #$02
$09B7    7E 09F0          JMP CHOOS
$09BA    B1 005C    NEXT3 CMP A NOZZ4
$09BD    2E 08            BGT NEXT4
$09BF    CE 0003          LDX #$0003
$09C2    86 03            LDA A #$03
$09C4    7E 09F0          JMP CHOOS
$09C7    B1 005D    NEXT4 CMP A NOZZ5
$09CA    2E 08            BGT NEXT5
$09CC    CE 0004          LDX #$0004
$09CF    86 04            LDA A #$04
$09D1    7E 09F0          JMP CHOOS
$09D4    B1 005E    NEXT5 CMP A NOZZ6
$09D7    2E 08            BGT NEXT6
$09D9    CE 0005          LDX #$0005
$09DC    86 05            LDA A #$05
$09DE    7E 09F0          JMP CHOOS
$09E1    CE 0006    NEXT6 LDX #$0006
$09E4    86 06            LDA A #$06
$09E6    7E 0A00          JMP SET
$09E9    01               NOP
$09EA    01               NOP
$09EB    01               NOP
$09EC    01               NOP
$09ED    01               NOP
$09EE    01               NOP
```

```
$09EF    01                  NOP
*
* Choose the best nozzle or nozzle combination.
*
$09F0    C6 02      CHOOS LDA B #$02       Double the value
$09F2    BD 0A70          JSR MULT         of req'd flow.
$09F5    E6 58            LDA B $58,X      If diff between
$09F7    E0 57            SUB B $57,X      nozzle capac is
$09F9    11               CBA              LE this value,
$09FA    2F               BLE LOW          choose smaller
$09FB    08         HIGH  INX              nozzle.
$09FC    4C               INC A
$09FD    01         LOW   NOP
$09FE    01               NOP
$09FF    01               NOP
*
* Turn on the chosen nozzle(s).
*
$0A00    FF 0055    SET   STX CHOIC        Store # of the
                                           nozzle chosen.
$0A03    CE 0DB0          LDX #$0DB0       Get nozzle
$0A06    08         MOR5  INX              control word
$0A07    80 01            SUB A #$01       from table.
$0A09    24 FC            BCC MOR5
$0A0B    E6 00            LDA B 0,X
$0A0D    F7 0402          STA B DDB        Send word to
                                           output on PIA.
$0A10    39               RTS              Return to main.
$0A11    01               NOP
$0A12    01               NOP
$0A13    01               NOP
$0A14    01               NOP
$0A15    01               NOP
*
* SUBROUTINE TO CHECK THE FLOWRATE TO THE NOZZLE CAPACITY,
* AND CORRECT CAPACITY VALUE IF NECESSARY.
*
$0A16    7D 005F    FLOW  TST FIRST        Skip this check
$0A19    26 06            BNE MOR6         during the
$0A1B    86 01            LDA A #$01       1st second.
$0A1D    B7 005F          STA A FIRST
$0A20    7E 0A42          JMP RETUR
$0A23    FE 0056    MOR6  LDX LACHO        Compare capac
$0A26    A6 58            LDA A $58,X      of nozzle in
$0A28    F6 0058          LDA B LAFLO      previous sec to
$0A2A    10         MOR6  SBA              the msd flow in
$0A2C    4A               DEC A            previous sec.
$0A2D    4D               TST A            If the diff
$0A2E    2E 0D            BGT REPLA        is more than
$0A30    B6 0058          LDA A LAFLO      one, go update
$0A33    E6 58            LDA B $58,X      the nozzle capac
$0A35    10               SBA              value to the
$0A36    4A               DEC A            flow which was
$0A37    4D               TST A            msd.
```

```
$0A38     2E 03                BGT REPLA
$0A3A     7E 0A42              JMP RETUR
$0A3D     B6 0058      REPLA   LDA A LAFLO
$0A40     A7 58                STA A $58,X
$0A42     FE 0055      RETUR   LDX CHOIC         Update value of
$0A45     FF 0056              STX LACHO         prev nozzle #
$0A48     39                   RTS               and return.
$0A49     01                   NOP
$0A4A     01                   NOP
$0A4B     01                   NOP
$0A4C     01                   NOP
$0A4D     01                   NOP
$0A4E     01                   NOP
$0A4F     01                   NOP
*
* INTERRUPT SUBROUTINE
*
$0A50     B6 0401      POLL1   LDA A CSA         If the clock
$0A53     2A 07                BPL POLL2         caused the
$0A55     7C 0050              INC CLOCK         interrupt, then
$0A58     B6 0400              LDA A DDA         increment clk,
                                                 clear inter.
                                                 If not, check
                                                 sensors.
$0A5B     3B                   RTI
$0A5C     B6 0403      POLL2   LDA A CSB         If flow caused
$0A5F     2A 03                BPL POLL3         it, increment
$0A61     7C 0051              INC FLOW          flow.
$0A64     84 40        POLL3   ANDA #$40         If feed caused
$0A66     27 03                BEQ CLRB          it, increment
$0A68     7C 0052              INC FEED          feed.
$0A6B     B6           CLRB    LDA A DDB         Clear interrupt.
$0A6C     3B                   RTI
$0A6D     01                   NOP
$0A6E     01                   NOP
$0A6F     01                   NOP
*
* MULTIPLY SUBROUTINE
*
* When this subroutine is called, the multiplier must be in
*    accumulator A, and the multiplicand in accumulator B.
* The result is put into accumulator A and is one byte
*    only.  If the result is greater than 255, then the
*    value of 255 will be the result.
*
$0A70     B7 0062      MULT    STA A MULT1
$0A73     86 08                LDA A #$08
$0A75     B7 0063              STA A MULT2
$0A78     4F                   CLR A
$0A79     B7 0064              STA A MULT3
$0A7C     74 0062      MX1     LSR MULT1
$0A7F     24 01                BCC MX2
$0A81     1B                   ABA
$0A82     46           MX2     ROR A
```

```
$0A83    76 0064              ROR MULT3
$0A86    7A 0063              DEC MULT2
$0A89    26 F2                BNE MX1
$0A8B    4D                   TST A              Is the result
$0A8C    2E 04                BGT MX3            more than 255?
$0A8E    B6 0064              LDA A MULT3        No-lower byte is
                                                 result.
$0A91    39                   RTS
$0A92    86 FF         MX3    LDA A #$FF         Yes- result is
                                                 255.
$0A94    39                   RTS
                              END
*
* TABLE OF THE LOG VALUES
*
$0D00 --
to
$0D38 --
*
* TABLE OF THE "A" EQUATION CONSTANT VALUES
*
$0D50 --
to
$0D5F --
*
* TABLE OF THE "B" EQUATION CONSTANT VALUES
*
$0D70 --
to
$0D7F --
*
* TABLE OF THE APPLICATION RATE VALUES
*
$0D90 --
to
$0D9F --
*
* TABLE OF THE NOZZLE CONTROL WORDS
*
$0DB0 01                                         Nozz 1 active.
$0DB1 02                                         Nozz 2 active.
$0DB2 04                                         Nozz 3 active.
$0DB3 08                                         Nozz 4 active.
$0DB4 06                                         Nozzs 2,3 active.
$0DB5 05                                         Nozzs 1,3 active.
*
* INTERRUPT ADDRESSES
*
$0FF8    0A50                                    Inter request
                                                 (clk or sensor).
$0FFA    0850                                    Software inter.
$0FFC    0850                                    Non-maskable int.
$0FFE    0850                                    Reset interrupt.
```

APPENDIX G

Table G1 Readouts on the monitor and the pulse counter for the drill test on the 0.79 cm diameter round-hole screen disk.

displacement (cm)	readout monitor	readout pulse counter	readout ratio	pulse counts /(cm·min)
1.9	0.0	11791	---	1241
2.5	11.8	11804	999	944
4.7	0.0	15132	---	644
6.6	0.0	23977	---	727
7.2	1.0	24700	24455	686

Note:
1. the displacement is offset from the center by 1 cm.
2. the readout ratio should be approximately 250 unless the monitor is not detecting all of the holes/slots.
3. the pulse counts/(cm·min) should be constant if the pattern is to give a good indication of the displacement.

Table G2 Readouts of the monitor and the pulse counter for the drill test on the 1.27 cm diameter round-hole screen disk.

displacement (cm)	readout monitor	readout pulse counter	readout ratio	pulse counts /(cm·min)
2.0	20.9	5234	251	523
	21.0	5241	249	524
4.7	26.2	5898	225	251
	26.3	5900	224	251
6.1	43.1	2435	56	80
	40.7	2439	60	80
7.6	20.8	16373	787	431
	14.1	16376	1161	431
8.8	13.0	19015	1464	432
	7.7	19010	2469	432

Table G3 Readouts on the monitor and the pulse counter for the drill test on the 2.54 cm diameter round-hole screen disk.

displacement (cm)	readout monitor	readout pulse counter	readout ratio	pulse counts /(cm·min)
2.5	15.7	3925	250	314
	15.7	3927	250	314
6.2	31.4	7856	250	253
	31.4	7856	250	253
7.6	15.7	3925	250	103
	15.7	3925	250	103
9.2	47.2	11123	236	242
	47.2	11136	236	242
11.2	36.8	8508	231	151
	39.0	8517	218	151
11.2	31.4	7859	250	140
	31.4	7862	250	140

Table G4 Readouts on the monitor and the pulse counter for the drill test on the unique hole disk.

disp. (cm) actual	approx	readout monitor	pulse counter	readout ratio	pulse counts /(cm·min)
2.8	3	7.9	1967	249	131
		7.9	1964	249	131
4.0	4	10.5	2619	249	131
		10.5	2619	249	131
4.6	5	13.1	3273	250	131
		13.1	3274	250	131
5.7	6	15.7	3928	250	131
		15.7	4204	268	140
5.8	6	15.7	3930	250	131
		15.7	3928	250	131
6.7	7	18.3	4580	250	131
		18.3	4578	250	131
8.4	8	34.2	7867	230	197 *
		34.0	7852	230	196 *
9.6	10	31.4	6902	220	138
10.1	10	26.2	6547	250	131
		26.2	6549	250	131
11.5	11	28.8	6545	227	119 **
		28.8	6546	227	119 **

* 12 holes were being detected here, rather than the expected 8.
** 10 holes were being detected here, rather than the expected 11.

Note: 4. The displacement to the nearest unit of sensitivity was used in the calculation of the count/(cm·min).

5. A small change is necessary in the amount of overlap necessary to have the correct number of holes read at any displacement. The holes must be placed and drilled with precision.

Table G5 Readouts on the monitor and the pulse counter for the drill test on the 11-slot disk.

disp. (cm) actual	approx	readout monitor	pulse counter	readout ratio	pulse counts /(cm·min)
2.7	3	7.9	1965	249	131
		7.9	2020	256	135
		7.9	1965	249	131
3.6	4	10.5	2620	250	131
		10.5	2620	250	131
6.3	6	15.7	3925	250	131
		15.7	3929	250	131
		15.7	3926	250	131
		15.7	3927	250	131
10.7	11	26.2	6549	250	119 ***
		26.2	6596	252	120 ***
		26.2	6542	250	119 ***
		26.2	6550	250	119 ***
		26.2	6548	250	119 ***
		26.2	6542	250	119 ***
		26.2	6551	250	119 ***

*** 10 holes were being detected here, rather than the expected 11.

Table G6 Readouts on the monitor and the pulse counter for the drill test on the 21-slot disk.

disp. (cm) actual	approx	readout monitor	pulse counter	readout ratio	pulse counts /(cm·in)
2.7	2.5	13.1	3303	252	264
		13.1	3271	250	262
		13.1	3274	250	262
3.5	3.5	18.4	4370	238	250
		18.3	4013	219	230
3.6	3.5	18.3	4200	230	240
		18.3	3900	213	223
		18.3	4585	250	262
6.2	6.	31.5	7882	250	263
		31.5	7860	250	262
		31.4	7853	250	262
10.0	10.	52.4	13104	250	262
		52.4	13099	250	262

APPENDIX H

Table H1 Readouts on the monitor and the pulse counter for the flowmeter calibration.

mass of water (g)	time (min)	readout monitor	readout counter	flow rate (L/min)	req'd monitor calib. value
5074	9.19	2.43	3223	0.55	79.03
5109	13.60	2.72	3606	0.38	71.09
5202	11.17	2.51	3323	0.47	78.44
5213	10.76	2.51	3317	0.48	78.61
5371	7.42	2.46	3248	0.72	82.64
5099	6.88	2.21	2920	0.74	87.35
5476	7.15	2.55	3372	0.77	81.28
5087	5.82	2.40	3366	0.87	80.23
5401	6.14	2.50	3305	0.88	81.77
5630	5.69	2.60	3444	0.99	81.96
4951	4.83	2.11	----	1.02	88.77
5118	4.96	2.17	----	1.03	89.13
5290	4.90	2.50	3323	1.08	80.09
5265	4.80	2.41	3186	1.10	82.69
5139	4.38	2.17	2878	1.17	89.46
5005	4.11	2.20	2918	1.22	86.11
5302	3.34	2.37	3135	1.59	84.68
5178	3.14	2.14	2830	1.65	91.55
5357	2.99	2.24	2965	1.79	90.52
5459	3.04	2.36	3128	1.80	87.55
5177	2.82	2.12	2810	1.84	92.22

Note: 1. the monitor readouts were taken at a monitor calibration value of 37.85
2. the "req'd monitor calib. value" is the calibration value required to give a readout of litres.

average flowrate = 1.05 L/min
flowrate range = 0.38 to 1.84 L/min

average req'd calib. value = 84.06
calib. value range = 71.09 to 92.22 (84.06-15% to 84.06+10%)

APPENDIX I

SIMULATION MODELLING OF THE FEEDROLL DISPLACEMENT

To obtain an indication of the movement of a feedroll on a forage harvester, and the feedroll displacement relative to a forage input to the harvester, a simple feedroll model was examined. The displacement of the upper feedroll on a forage harvester was simulated utilizing the computer program, CSMP (Continuous Simulation Modelling Program). The forage harvester was treated as a spring-mass-damper system, with the spring and damper representing the tires on the harvester. The feedroll was treated as a spring-mass system, with a spring representing the tension springs between the feedroll and the harvester, and a spring (in compression) representing the crop.

Simulations were done of a forage harvester travelling over a bumpy field. One simulation was done with no forage input to the harvester, and a second simulation had a swath of forage being input into the feedrolls.

When compared with the bumps on the field, the displacement of the harvester relative to flat ground was small, probably due to the large mass of the harvester. The harvester displacement had a cycle frequency of approximately one half the frequency of the bumps on the ground.

The feedroll displacement (relative to the harvester, or to flat ground) was greater than the harvester displacement, but had the same cycle frequency. The feedroll

displacement patterns for the two simulation runs were similar. The frequency and shape of the displacement peaks in the run involving forage input were almost identical to the frequency and curve shape during the no-forage run. The amplitude of the feedroll displacement fluctuation during the no-forage run was significant; however, the displacement amplitude with a forage input was greater. Since there was significant feedroll displacement during the no-forage run, the displacement of the feedroll during the run with forage cannot be attributed only to the forage passing through the harvester.

Further analysis and simulations would be required to derive the true mathematical relationship between the feedroll displacement and the forage feed rate through a harvester.